The Equivalent Volume of a Reverberation Chamber

Jamilla Balint[1], Gerhard Graber[1], Herbert Hahn[2]
[1] *Signal Processing and Speech Communication Laboratory, Graz University of Technology*
8010 Graz, Email: balint@tugraz.at, graber@tugraz.at
[2] *TWB Buch GmbH, 1180 Vienna, Email: hahn@akustikbuch.at*

Introduction

Measurements of the absorption coefficient α in a reverberation chamber show large deviations over the full frequency range. This fact has been proven by many round robin tests over the last few decades [1],[2]. The absorption coefficients measured in different reverberation chambers are not only poorly reproducible but also exceed values above $\alpha = 1$. Due to the edge effect [3] the absorption coefficient can reach values slightly over $\alpha = 1$, values of $\alpha \approx 1.6$ however are not reasonable from a physical point of view. Past round robin tests tried to eliminate certain kind of measurement uncertainties but the issue has not been resolved. The question still remains if it is possible to measure the true absorption coefficient in a reverberation chamber [4, p.114].

This research started with the evaluation of the diffuse sound field in a reverberation chamber. We measured the reverberation time in 110 positions at three different heights in the chamber for two cases. The first case was without any diffusers installed and the second case was with 12 suspended diffusers which were mounted according to the procedure described in Annex A of ISO 354 [5]. For this procedure we measured the reverberation time with 0, 4, 9 and 12 suspended diffusers and calculated the absorption coefficient of a highly absorbent sample ($\alpha > 0.9$). This research shows that without diffusers the sound field in a reverberation chamber in a frequenqy range of $f > 500$ Hz is already highly diffuse.

Measurements

The equivalent absorption area A_T of a sample is calculated by measuring the reverberation time in a reverberation chamber with and without the sample:

$$\begin{aligned} A_T &= A_2 - A_1 \\ &= 55.3 \cdot V \cdot \left(\frac{1}{c_2 \cdot T_2} - \frac{1}{c_1 \cdot T_1} \right) - 4 \cdot V \cdot (m_2 - m_1), \end{aligned} \tag{1}$$

where A_T denotes the equivalent absorption area of the sample, A_1 and A_2 the equivalent absorption area of the reverberation chamber without and with the sample, V the total volume of the chamber, c_1 and c_2 the speed of sound with respect to the temperature during the measurements, T_1 and T_2 the measured reverberation time without and with the sample and m_1 and m_2 the attenuation of the sound due to dissipation according to ISO 9613-1. With the surface area of the sample, it is possible to calculate the absorption coefficient α:

$$\alpha = \frac{A_T}{S}, \tag{2}$$

The diffuse sound field in the reverberation chamber was evaluated according to Annex A of ISO 354. The standard states that the absorption coefficient between 500 Hz and 4000 Hz of a sample increases with increasing number of diffusers and approximates a maximum value when the optimum diffuse sound field is reached.

The mounted diffusers were made out of 5mm thick acrylic glass with a surface related mass of 6.5 $\frac{kg}{m^2}$. The resulting 12 diffusers had a total surface area (both sides) of 39.44 m^2, which is 16.8% of the total surface area of the chamber. Recommended values according to ISO 354 for the total surface (both sides) of the diffusers are 15%-25% of the total surface area of the reverberation chamber.

When we carried out the first measurement series according to ISO 354 with 0 diffusers, the resulting absorption coefficients were $\alpha \approx 1$ (see fig. 1 and fig. 2). Then we repeated the measurements with 4, 9 and 12 diffusers until the absorption coefficient reached a mean value of $\alpha \approx 1.2$ (for f < 1000 Hz: $\alpha \approx 1.35$, see fig. 2). We stopped adding diffusers when the absorption coefficient reached a maximum value for $f < 3000$ Hz. For $f > 3000$ Hz the absorption coefficient still increased slightly with 12 diffusers. In [6] the same measurement procedure according to ISO 354 was described. The absorption coefficients without diffusers in the room were $0.9 \leq \alpha \leq 1.2$ and increased up to $1.1 \leq \alpha \leq 1.4$ when diffusers were added. In [6] different arrangements of diffusers were evaluated (varying positions, quantities, and sizes of diffusers). The absorption coefficient fluctuated randomly over the entire frequency range between $1 \leq \alpha \leq 1.4$.

Additionally to the measurements according to ISO 354, we measured the reverberation time in the chamber at 110 positions at three different heights in the empty room with 0 diffusers installed as well as with 12 diffusers. Results for a height of $h = 180$ cm for the $\frac{1}{3}$-octave bands of 160 Hz and 1250 Hz are shown in fig. 3 and fig. 4. Without diffusers, the reverberation time at 125 Hz fluctuates among different microphone positions between $3.7s \leq T \leq 5.6s$, and with diffusers between $3.8s \leq T \leq 4.6s$ (see fig. 3). The fluctuation decreases from 1.9 s to 0.9 s. In case of 1250 Hz, the reverberation time fluctuates without diffusers between $5.6s \leq T \leq 6.3s$, and with diffusers between $5.2s \leq T \leq 5.9s$ (see fig. 4), so in both cases the

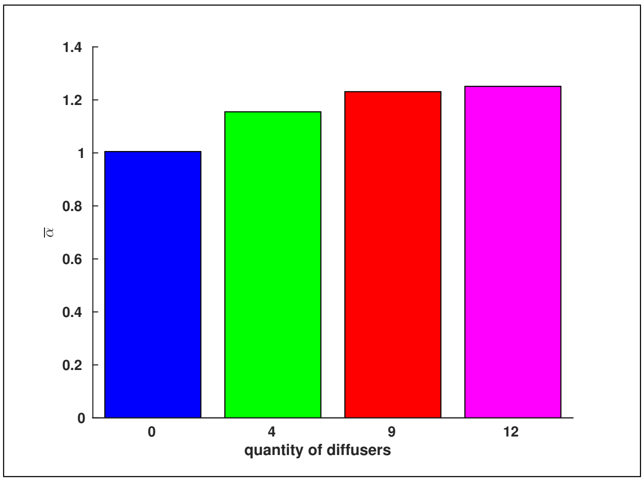

Figure 1: Mean value of the absorption coefficient (between 500 Hz and 4000 Hz) with increasing number of diffusers.

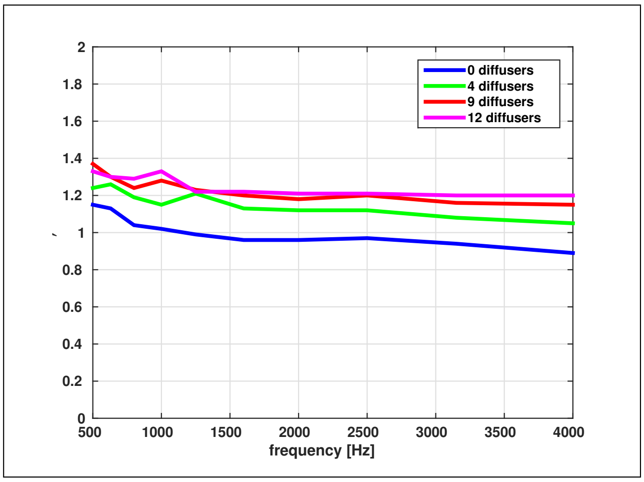

Figure 2: Absorption coefficient with increasing number of diffusers from 500 Hz to 4000 Hz.

fluctuation stays at 0.7 s. The reverberation time declines slightly at 1250 Hz but there is no difference in the fluctuation interval. The evaluation of the varying reverberation time between different microphone positions indicates that the diffusers only have an impact in the frequency range $f < 300$ Hz and do not change the diffusivity of the sound field for $f > 300$ Hz.

Diffuse Sound Field

Remmers, Kappelmann and Blau also tried in [7] to evaluate the diffusivity of the sound field with different methods. They measured the sound pressure level at 198 points in the reverberation chamber without any diffusers and with diffusers. They also measured the sound intensity at three different points in the chamber. The only conclusion they could draw from their measurements was that differences in the sound field were only visible in the low frequency range below 300 Hz. In [7] it was only possible to verify the increased diffusivity of the sound field due to the diffusers when performing the evaluation procedure according to Annex A of ISO 354 but not with any other measurement method.

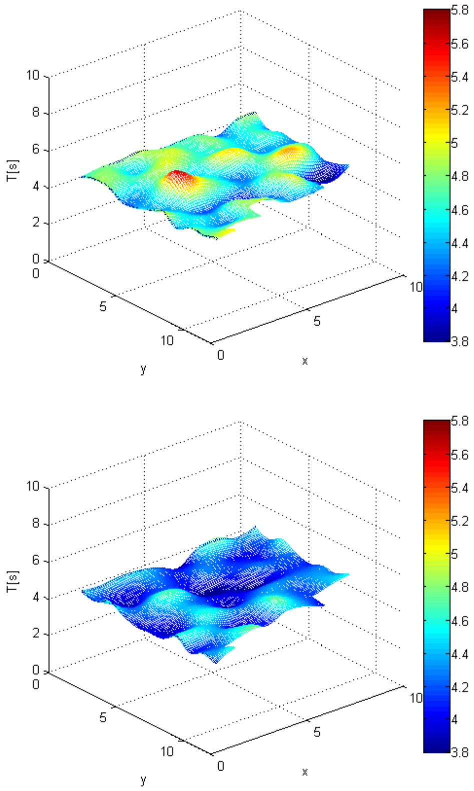

Figure 3: Reverberation Time at 160 Hz for a height of h = 180 cm, top: chamber without any diffusers, bottom: chamber with 12 diffusers

Vercammen explains in [8] and Jachmann in [9] that diffusers are essential for a reverberation chamber. When no diffusers are installed, a horizontal sound field builds up and not enough sound waves hit the sample on the ground. When diffusers are installed, the sound waves are redirected more to the sample on the ground rather than being reflected between two parallel walls.

The basic assumption for evaluating the diffuse sound field described in Annex A of ISO 354 lies in Sabine's formula for the reverberation time. Sabine's formula for the reverberation time is given by:

$$T = \frac{4 \cdot 6 \cdot ln(10) \cdot V}{c \cdot \alpha \cdot S}, \tag{3}$$

where the term $6 \cdot ln(10)$ describes the 60 dB decay and the factor 4 considers the angle dependency of the absorption coefficient[1].

In this section we take a closer look at the formula and simplify it for the case of a constant temperature of 20°C (in this case the speed of sound is $c = 343\frac{m}{s}$):

$$T = 0.161 \cdot \frac{V}{A}, \tag{4}$$

where T denotes the reverberation time in the chamber, V the total volume of the chamber and A the equivalent absorption area of the total surface. The equivalent absorption area A as well as the reverberation time T are

---

[1] For a detailed derivation see pp. 9-27 of [4]

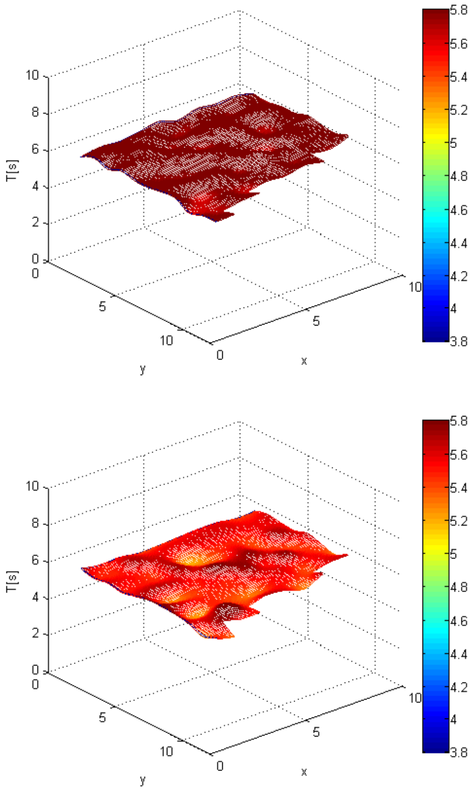

Figure 4: Reverberation Time at 1250 Hz for a height of h = 180 cm, top: chamber without any diffusers, bottom: chamber with 12 diffusers

frequency-dependent:

$$T(f) = 0.161 \cdot \frac{V}{A(f)} \tag{5}$$

To calculate the equivalent absorption area, we rearrange the equation:

$$A(f) = 0.161 \cdot \frac{V}{T(f)} \tag{6}$$

When diffusers are added to the room, the reverberation time decreases slightly [6], [9]. The equivalent absorption area becomes bigger than the actual surface area of the sample, and this is not plausible from a physical point of view (except the deviation due to the edge effect). To make the equation physically plausible (for the case when diffusers are added), we roughly restrict the equivalent absorption area to the surface area of the sample (this means that $\alpha \approx 1$):

$$A(f)\Big|_{\overset{!}{\approx} S} = 0.161 \cdot \frac{V_e}{T(f)} \tag{7}$$

When we restrict the equivalent absorption area, at the same moment it is necessary to change the volume V of the reverberation chamber to the acoustically equivalent volume V_e. The volume V_e becomes the unknown factor in the equation:

$$V_e = 0.161 \cdot A(f)\Big|_{\overset{!}{\approx} S} \cdot T(f) \tag{8}$$

Since the term on the right side of eq. 8 is frequency-dependent, the volume $V_e(f)$ becomes frequency-dependent too:

$$\Rightarrow V_e(f) = 0.161 \cdot A(f)\Big|_{\overset{!}{\approx} S} \cdot T(f) \tag{9}$$

Equation 9 directly leads to the formulation of the hypothesis described in the following section.

Hypothesis

We assume that the equivalent absorption area $A_T(f)$ of a sample is independent of the amount of diffusers in the chamber and is roughly limited to the surface area of the sample. When we add diffusers, the equivalent absorption area $A_T(f)$ stays constant and the volume of the reverberation chamber has to be replaced with a reduced, frequency-dependent, acoustically equivalent volume $V_e(f)$:

$$V_e(f) = \frac{A_T(f)}{55.3 \cdot \left(\frac{1}{c_2 \cdot T_2(f)} - \frac{1}{c_1 \cdot T_1(f)} \right)} \tag{10}$$

In fig. 5 the volume V of the empty chamber with zero diffusers is constant. However, at the moment we put diffusers into the chamber and assume that the equivalent absorption area stays constant, the volume decreases and becomes frequency-dependent.

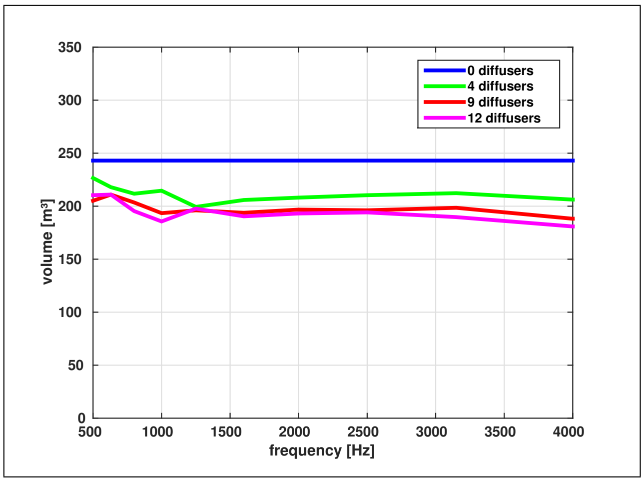

Figure 5: Decreasing, equivalent Volume of the reverberation chamber with increasing amount of diffusers.

The consequences of the hypothesis are discussed in the following section.

Discussion and Conclusion

For f < 300 Hz, the spatial fluctuation of the reverberation time decreased with diffusers in the reverberation chamber. The diffusers improved the diffusivity of the sound field for the frequency range of f < 300 Hz. The diffusers have an impact on the sound field in the low frequency range, where the density of room modes is very low. The spatial fluctuation of the reverberation time can be reduced in the low frequency range by hanging diffusers from the ceiling.

For $f > 300$ Hz the diffusers did not change the spatial fluctuations of the reverberation time. This indicates that the sound field without diffusers is already highly diffuse. For $f > 300$ Hz the diffusers reduced the reverberation time but did not change the spatial fluctuation. The research of [7] also showed that the reverberation time decreases with diffusers but the change between the sound field with and without the diffusers was also only visible in the low frequency range of $f < 300$ Hz.

We might have to revise our assumptions of the diffusivity of the sound field and the absorption coefficient of a sample. If we assume that the absorption coefficient is restricted to $\alpha \approx 1$, we have to consider an acoustically equivalent volume $V_e(f)$ of the reverberation chamber and the following consequences:

- We have to calculate the equivalent Volume $V_e(f)$ of reverberation chambers equipped with diffusers.
- Absorption coefficients have to be recalculated with the new, reduced, frequency-dependent volume $V_e(f)$.
- Absorption coefficients result in smaller values.

The reproducibility of absorption coefficients between different laboratories is very poor. The hypothesis in this research assumes that the diffusers reduce the actual volume of the chamber. The recommendation in ISO 354 about the exact size, position and amount of diffusers in a reverberation chamber is not precise. As a consequence the diffusers are mounted in various ways in every reverberation chamber and the deviations of the absorption coefficients between different laboratories are very random. The diffusers reduce the fluctuations in the reverberation time in the low frequency range but the impact of reducing the volume of the reverberation chamber has to be compensated.

According to the hypothesis, when we measure absorption coefficients in empty reverberation chambers with no diffusers installed, the absorption coefficients are reproducible. This is going to be evaluated in a round robin test.

Acknowledgements

This material is based upon work supported by the TWB Buch GmbH. We would like to thank Dr. Christiane Erten for the collaboration and providing the reverberation chamber for measurements.

References

[1] Vercammen, M.L.S.: Improving the accuracy of sound absorption measurements according to ISO 354. Proc. of the Int. Symp. on Room Acoustics, ISRA 2010

[2] ASTM - European sound absorption round robin tests. Internal Report, 1990

[3] Bruin, Alex de: Calculation of the edge effect of sound-absorbing structures. Doctoral Thesis, Delft University of Technology 1967

[4] Cremer, L.: Die wissenschafltichen Grundlagen der Raumakustik – Band II: Statistische Raumakustik. S. Hirzel Stuttgart, 1961

[5] ISO 354: Acoustics – Measurement of sound absorption in a reverberation chamber. 2003

[6] Glaser, W.: Messung des Schallabsorptionsgrades von Materialien, die in der Lärmbekämpfung zur Anwendung kommen. Diploma Thesis, University of Technology Vienna, 1985

[7] Remmers, H.; Kappelmann, M.; Blau, M.: Messung und Bewertung der Diffusität des Schallfeldes in einem Hallraum. DAGA 2006

[8] Vercammen, M.; Lautenbach, M.: Can we use the standard deviation of the reverberation time to describe diffusion in a reverberation chamber? AIA-DAGA 2013

[9] Jachmann, H: Entwurf und Erprobung eines Modell-Hallraums im Maßstab 1:10. Diploma Thesis, Hochschule Mittweida, 2006