Influence of ground reflections and loudspeaker directivity on measurements of in-situ sound absorption

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Sound absorption is a relevant property for the acoustic quality of noise barriers. The Adrienne method is the most used in-situ measurement method in Europe for testing the acoustic performance of noise reducing devices in real life conditions. This method was introduced in 2003 with the technical specification CEN/TS 1793-5 [1] and the development of this method is now one of the main objectives of the European project QUIESST. In the frame of this project AIT Mobility has performed a first measurement campaign in order to investigate the influence of ground reflections and the role of the sound source for measurements of sound absorption in the near field. Two different sound sources and different microphone heights have been used for analyzing the influence of the source directivity and the role of ground reflections. The study shows that particular attention should be paid to the source directivity and to the microphone position, while the ground reflection does not seems to represent a problem for the method at all.

1 Introduction

The present paper describes the first investigations carried out by AIT in the frame of the WP3 of the EU project QUIESST. During this measurement campaign the influence of ground reflection and the influence of loudspeaker directivity have been investigated with a modified version of the Adrienne method. The primary goal of the presented measurements was to analyze if ground reflections are still present in the reflected impulse response function (IRF) after subtraction and windowing in the time domain was applied to the function.

The investigations were performed using two different sound sources and different microphone heights, in order to investigate also the influence of the source directivity on the results.

2 Overview of the Adrienne method

In this section a short overview of the basic principle of the Adrienne method will be given. A full description of the measurement procedure can be found in the European Standard CEN/TS 1793-5 [1]. For a detailed overview of the method publication [2] should be taken into account.

For determining the reflection properties of a noise barrier, a sound source is placed on the side of the device under test facing the traffic in a distance of d_S = 1.5 m and a height h_S of the half wall height h_B using a tripod and a movable tripod head. Between this loudspeaker and the surface of the noise barrier, a microphone is placed d_{SM} = 1.25 m away from the loudspeaker using a rigid joint. Thus, vertical and horizontal rotations can be performed without changing the absolute distance between loudspeaker and microphone. Overall, by rotating the sound source and therewith the microphone in the horizontal respectively vertical plane from 50° to 130° by steps of 10° (with the 90°-position facing the wall directly) 17 different measurement positions can be adjusted.

Now the impulse response function (IRF) is determined using the MLS (Maximum Length Sequence) technique in all of these positions [2]. This function contains the impulse response function of the loudspeaker as well as the IRF reflected from the noise barrier. Additionally, parasitic components, e.g. by reflections from the ground, are included in this function.

Figure 1 show an exemplary IRF of a reflection measurement. In this picture different peaks are present: the first peak is the direct component, the second one is the component reflected from the noise barrier, and then a series of parasitic components are reflected from the ground or from other objects.

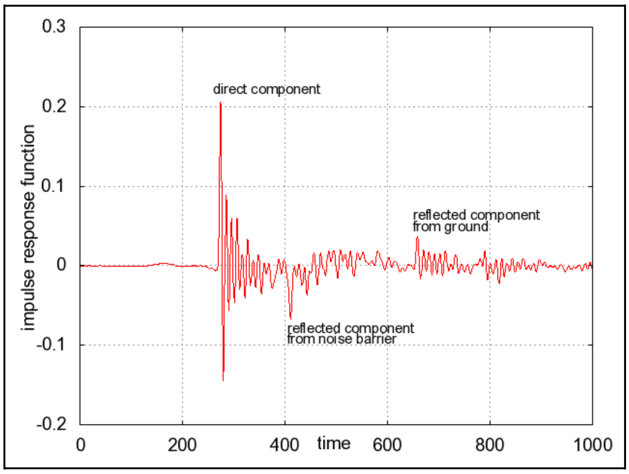

Figure 1: Exemplary IRF of a reflection measurement.

For eliminating the direct component of the impulse response function, an additional IRF measurement is performed with the sound source – microphone combination facing the free field. Then this free-field IRF is windowed using the so-called Adrienne window specified in [1] to exclude parasitic reflections. By subtracting this windowed free-field IRF from the gathered reflection measurements and thereafter windowing the resulting function using the Adrienne window, finally an IRF containing only the reflected component can be determined. Next, these functions are corrected with respect to their different propagation parts, Fourier transformed, accumulated to third-octave bands, and related to the free-field spectrum.

Finally, the so-called Reflection Index RI_j as a function of third-octave bands can be calculated by averaging over all measurement positions of a rotation. The mathematical formulation of the RI_j is given in equation (1).

$$RI_j = \frac{1}{n_j} \sum_{k=1}^{n_j} \frac{\int_{\Delta f_j} \left| F\left[t \cdot h_{r,k}(t) \cdot w_r(t) \right] \right|^2 \mathrm{d}f}{\int_{\Delta f_j} \left| F\left[t \cdot h_i(t) \cdot w_i(t) \right] \right|^2 \mathrm{d}f} \tag{1}$$

Where:

$h_{i(t)}$ reference free-field sound pressure wave;

$h_{r,k(t)}$ reflected sound pressure wave at the k-th angle;

$w_{i(t)}$ reference free-field sound wave time window (Adrienne window);

$w_{r,k(t)}$ reflected sound wave time window (Adrienne window);

t time from the beginning of the impulse response;

Δfj	j-th 1/3 octave frequency band (from 160 Hz to 5000 Hz);
nj	number of angles on which to average;
F	symbol of the Fourier transform.

The reflection index RI can be also weighted using the road traffic noise spectrum from EN 1793-3 [3] to calculate the sound reflection index DL_{RI} in decibels. This index describes the absorption properties of the barrier.

The definition of the reflection index DL_{RI} is described in equation (2).

$$DL_{RI} = -10 \cdot \lg \left[\frac{\sum_{i=4}^{18} RI_i \cdot 10^{0.1 \cdot L_i}}{\sum_{i=4}^{18} 10^{0.1 \cdot L_i}} \right] \qquad (2)$$

whereas L_i are the relative A-weighted sound pressure levels (dB) of the normalized traffic noise spectrum in one-third-octave bands as defined in [3]. As can be seen in equation (2), lower frequency band from 100 Hz to 200 Hz are not taken into account in the calculation of DL_{RI}.

3 Measurement setup

The measurements were performed on the premises of AIT in Vienna (Austria) during the summer 2010 on a flat wall of the building. The air temperature was 28 °C while the wall temperature was 25°C. The wall tested was about 5 m wide until the next point of discontinuity and was 6 m high. Figure 2 show the measurement setup for both used sound sources.

Figure 2: Measurement setup during measurements with directional source (left) and using the omnidirectional source (right).

Impulse response functions (IRF) were measured using a line array with 3 microphones parallel to the building wall in the following configurations: loudspeaker height 2 m and 3 m, height of the microphone array relative to the loudspeaker height -0.4 m, 0 m, 0.4 m and 0.8 m (meaning 1.6 m, 2 m, 2.4 m and 2.8 m for 2.0 m loudspeaker height and 2.6 m, 3 m, 3.4 m and 3.8 m for 3.0 m loudspeaker height).

Free-field measurements were performed with a loudspeaker height of 2.4 m and microphone array heights of 2.0 m, 2.4 m, 2.8 m and 3.2 m.

3.1 Loudspeakers and microphones

For the purpose of investigating the source directivity two different loudspeakers were used: a JBL 2123H loudspeaker with a Blaupunkt GTA 200 amplifier and a B&K Omnisource with a B&K 2716 amplifier. The microphones used were of the type GRAS 40AF with Norsonic 1201 preamplifiers, as analyzer respectively recorder a B&K 3560B real time analyzer was used.

The impulse response functions were measured using the MLS technique with a MLS length of 216-1=65535 samples, with a sampling rate of 65536 Hz of the analyzer resulting in a MLS length of ~1 second. The IRF was measured over 16 repetitions of the MLS.

The most ostensible difference between these two sound sources is their different directional characteristic. The B&K Omnisource is designed especially to emit a spherical wave, whereas the JBL 2123H possesses a directional sound radiation.

It also has to be stated that the B&K Omnisource does not comply with all requirements of the Technical Specification [1] as its free-field IRF is notably longer than the demanded 3 ms. Also, as shown later, the white noise of the MLS is not well reproduced by the B&K Omnisource. Figure 3 shows the two used loudspeakers.

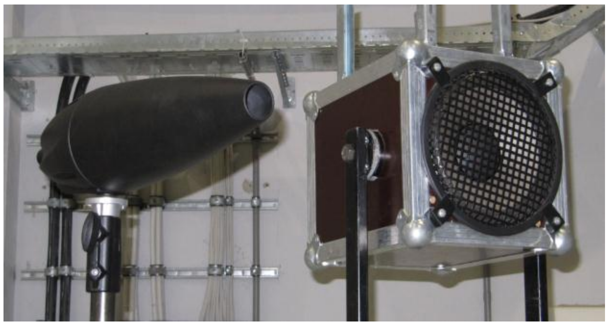

Figure 3: B&K Omnisource (left) and JBL 2123H (right).

The loudspeaker directivity was measured horizontally for both loudspeakers. Figure 4 shows the directivity diagram for both loudspeakers.

Additionally, an Adrienne measurement according to CEN/TS 1793-5 was performed using the JBL loudspeaker performing horizontal as well as vertical rotation.

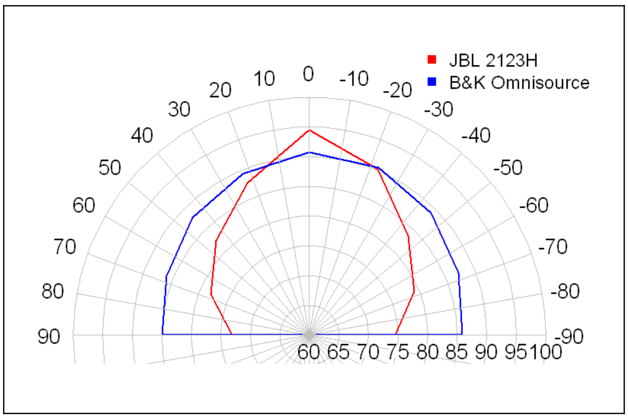

Figure 4: Loudspeakers used and measured directivity.

4 Results on ground reflections

For geometrical reasons the most vulnerable measurement configuration to ground reflections was the configuration with a loudspeaker height of 2 m and microphone heights of 1.6 m, where the distance to the reflecting surfaces was smaller.

Figure 5 shows the IRF before and after windowing using the Adrienne window, for the three microphones.

Even in this case no relevant ground reflections are present in the windowed IRF. However, it can be seen that ground reflections arrive at the microphone position shortly after the end of the applied Adrienne window, or even in the end of the right-sided Blackman-Harris part of the time window.

In the case of having the microphone and/or loudspeaker positions nearer to the ground, it will include ground reflection components in the windowed IRF (under the condition of the same Adrienne window length).

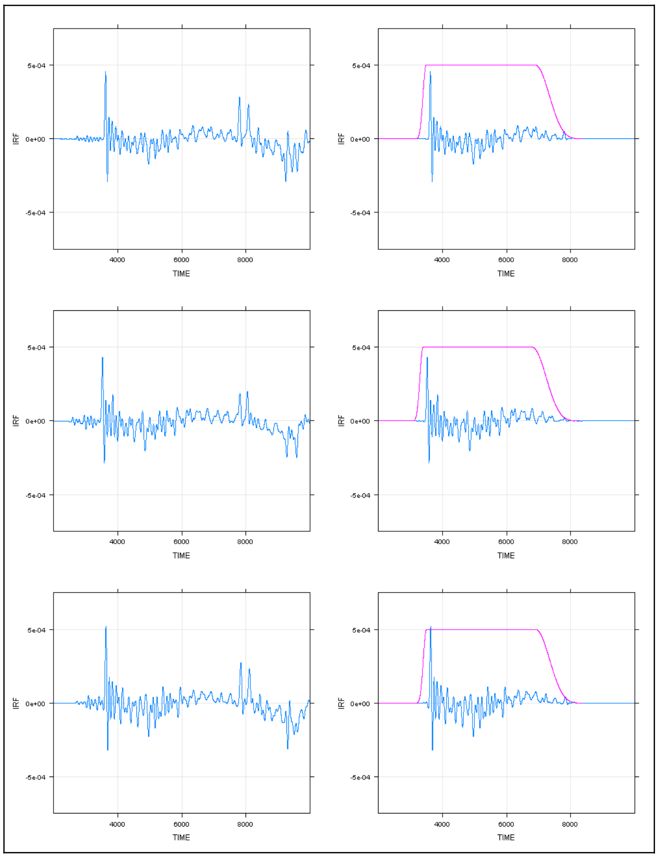

Figure 5: Top to bottom: left, middle and right microphone, left & right: before and after Adrienne windowing; ground reflections can be seen at approx. timestamp 8000, and are excluded after Adrienne windowing; loudspeaker height: 2 m, microphone height: 1.6 m.

Figure 6 and Figure 7 show the contour plot of the frequency distribution versus the Adrienne window length on the ordinate for both used sound sources. As a signal containing a pure echo:

$$y(t) = x(t) + ax(t - t_0)\,. \tag{3}$$

which results in the following frequency distribution

$$|Y(f)| = \sqrt{1 + a^2 + 2a\cos(2\pi f t_0)}\,|X(f)|\,. \tag{4}$$

with an oscillatory term imposed on |X(f)|, the clearly visible “rippling” beginning at main-part Adrienne window lengths of over 5.5 ms in Figure 6 implies the arrival of parasitic reflection components for longer window lengths.

As $t_0 = 1/\Delta f^{ripple}$ and therefore $\Delta s^{echo} = c*t_0$, a mean distance between the arrival of the (wanted) reflected signal and parasitic reflections (for a main-part Adrienne window length of 6.5 ms) can be calculated.

The gained result of $\Delta s^{echo} = 2.41$ m coincides well with the calculated arrival of the first ground reflections after $\Delta t^{ground} = 7.17$ ms and therefore $\Delta s^{ground} = 2.44$ m.

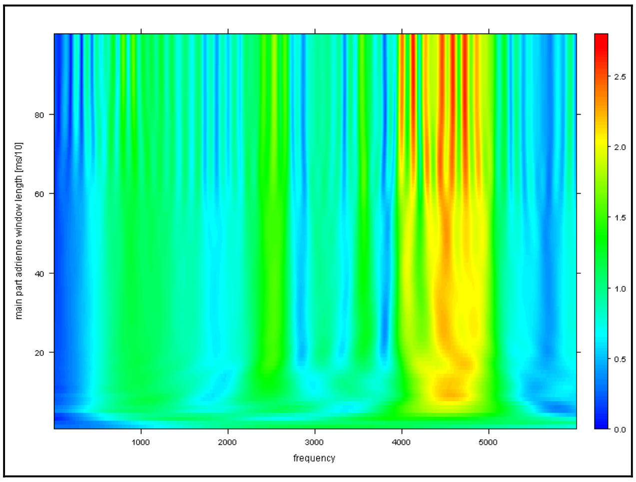

Figure 6: Influence of the Adrienne window length on ground reflections for directional loudspeaker using loudspeaker and microphone height of 2 m, a loudspeaker - microphone distance of 1.25 m and a microphone – wall distance 0.25 m; the Adrienne window marker point was placed at the beginning of the reflected component. The Adrienne main window length has a unit of [ms/10].

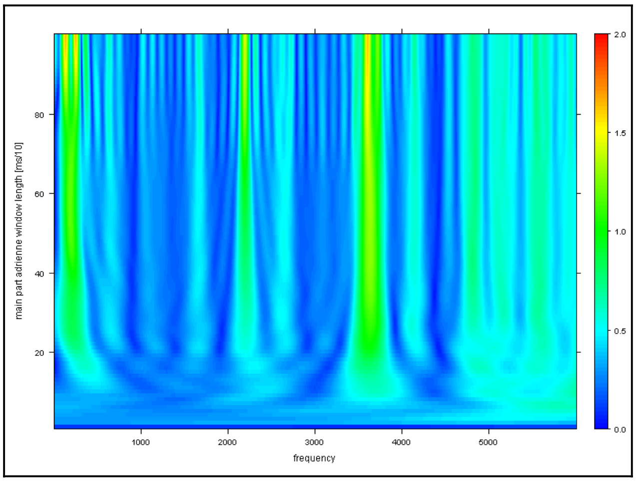

Figure 7: Influence of the Adrienne window length on ground reflections for the omnidirectional loudspeaker using loudspeaker and microphone height of 2 m, with a loudspeaker – microphone distance of 1.25 m, and a microphone – wall distance of 0.25 m; the Adrienne window marker point was placed at the beginning of the direct component; approx. 2.5 ms after the direct component, first reflections from the cone in front of the loudspeaker membrane can be seen; at a main window length of ~7 ms ground reflections begin.

5 Results on directivity influence

When emitting a highly directive sound wave to a highly reflective surface (as in the present case), and measuring the reflected sound wave under a certain angle, it is possible that the reflected sound energy (green line in Figure 8) is higher than the direct sound energy that was emitted at a larger angle (red line in Figure 8). Figure 8 shows the different emission directions for specular reflection for the measurement setup used in this study. In Table 1 the differences of the emitted sound pressure level between 12° and 18° are shown for the directional sound source (JBL).

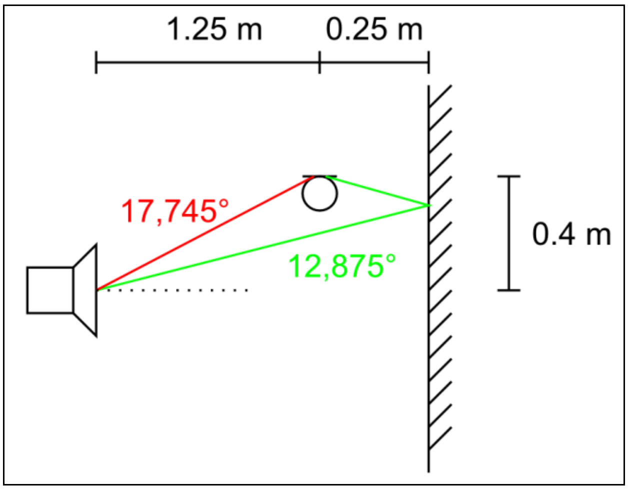

Figure 8: Different emission directions for specular reflection: in red the travel path of the direct component, in green travel path of the reflected component.

Table 1: Differences of the emitted sound pressure level between 12° and 18°.

1/3-octave-band	**ΔL [dB]**
100	0,2
125	0,0
160	-0,1
200	-0,3
250	0,0
315	-0,2
400	-0,3
500	-0,2
630	-0,1
800	-0,5
1000	-0,5
1250	-0,6
1600	-0,7
2000	-0,9
2500	-1,9
3150	-1,6
4000	-2,6
5000	-4,4
6300	-2,4
8000	-2,5
10000	-2,1

Moreover when looking at the measured loudspeaker directivity in one-third octave band resolution, high differences in the emitted sound power levels between the angles of approx. 12° and 18° are present between 2.5 and 6.3 kHz as well as shown in Table 1. Figure 9 shows the measured directivity of the directional loudspeaker.

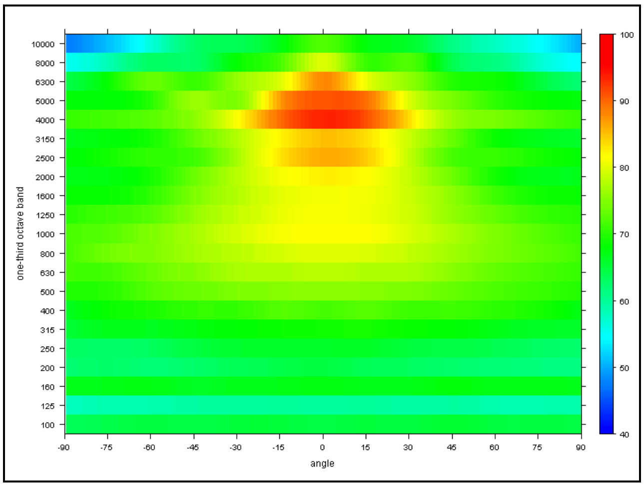

Figure 9: Directional characteristic of the directional loudspeaker JBL (measured): between at 2.5 kHz and 6.3 kHz a relevant difference is shown between the angles 12° and 18°.

Figure 10 and 11 show the results of the reflection Index RI for the 9 microphone position used at 2 m height. The influence on the reflection index RI of the source can be easily seen especially at high frequencies for the side microphone positions.

A possible work-around of this problem could be the recording of two different free-field IRs, one only used for subtraction with a loudspeaker-microphone distance of 1.25 m, and one as reference value with a distance of 1.75 m, where the distance of 1.75 m is needed in order to have the same angle of incidence for direct and reflected wave. Using this method, also no geometric propagation corrections need to be applied. The method using two different free-field IRs needs to be investigated in more detail and will be presented in further publications.

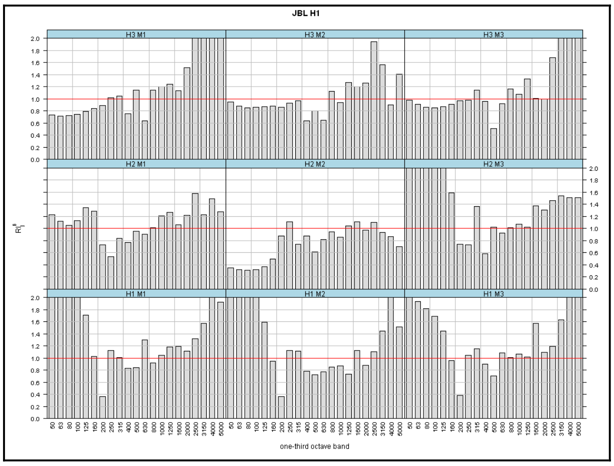

Figure 10: RI of the 9 measurement positions when looking to the wall for the directional loudspeaker JBL.

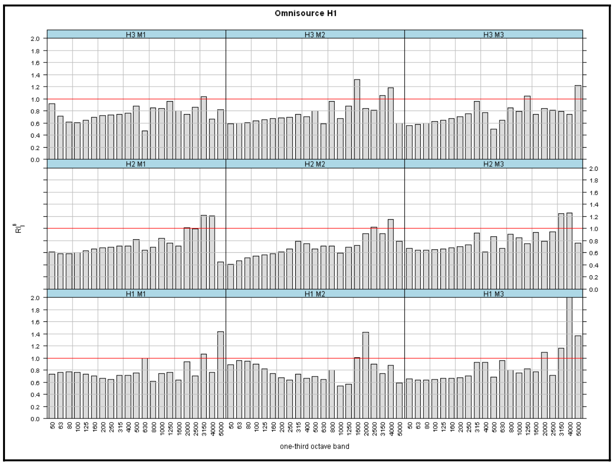

Figure 11: RI of the 9 measurement positions when looking to the wall for the omnidirectional loudspeaker Omnisource.

6 Conclusion

The primary goal of the presented measurements was to analyze if ground reflections are still present in the reflected impulse response function (IRF) after subtraction and windowing in the time domain was applied to the function. The influence of the Adrienne window length on ground reflections has been also analyzed. The most vulnerable configuration to ground reflections was obviously the configuration with a loudspeaker height of 2 m and microphone heights of 1.6 m. As shown in section 4, also in this case no relevant ground reflections are present in the windowed IRF. However, it can be seen that ground reflections arrive at the microphone position shortly after the end of the applied Adrienne window (or even in the end of the right-sided Blackman-Harris part of the time window), so microphone and/or loudspeaker positions nearer to the ground will include ground reflection components in the windowed IRF (under the condition of the same Adrienne window length). For this reason it can be concluded that the maximum window length should not exceed 7.9 ms.

As additional topic an analysis of the influence on the reflection index RI of the source directivity was also performed. A highly directional sound source emits different energy amounts in the direction of the microphone and in the direction of the geometrical reflection spot on the wall has been compared with the omnidirectional loudspeaker. When looking at the measured loudspeaker directivity in one-third octave band resolution, high differences in the emitted sound power levels between the angles of approx. 12° and 18° start at 2.5 kHz. For this reason particular attention should be paid to the directivity characteristics of the sound source. Further and more detailed investigations are planned on this topic; the results will be presented at future conferences.

Acknowledgments

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References

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