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IN SITU MEASUREMENT OF THE ABSORPTION COEFFICIENT AT NORMAL INCIDENCE USING MLS-SEQUENCES AND 1 OR 2 MICROPHONE TECHNIQUES

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ABSTRACT
For the in situ determination of acoustical properties (surface impedance, reflection- and absorption coefficient) of sound-absorbing materials, 1 or 2 microphone techniques are most widely used. An experimental system is developed for studying some techniques in a semi-anechoic room to examine the applicability of these techniques in real in-situ environments on (locally reacting) finite size test-materials. All these techniques are based on measured impulse-responses at 1 or 2 locations close to the test-surface. These responses are obtained using pseudo-random MLS-sequences. Low and high frequency limits are studied for the 'subtraction' technique and the 'impulse sharpening' technique (both 1 microphone) and for the 'spherical decoupling' technique (2 microphones). The techniques are compared and evaluated for their in-situ applicability. Some rules of thumb and guidelines are deduced.

1 - INTRODUCTION

For measuring the absorption coefficient of acoustical materials in-situ, 'impulse-techniques' are most applicable since they make it possible to remove unwanted reflections from the recorded signal. Experiments have been made in the past using spark-sources, gunshots, recorded pulses and tone-bursts. However, measuring impulse-responses indirectly using e.g. pseudo-random MLS-sequences, has been proved to be superior, due to the fact that they are perfectly reproducible, have a high dynamic range and can be applied in noisy environments. Time-windowing, subtraction of free-field signals or other techniques (e.g. cepstral deconvolution) can remove unwanted signals.

Determining absorption coefficients is a matter of separating the reflected part from de direct part of the impulse-response, measured in front of a surface sample. Garai [1] used 1 microphone and time-windowing for this separation. A short source impulse-response or a large distance from the wall is necessary. To cope with these problems, Mommertz [2] developed a technique where the direct signal (measured previously in free-field conditions) can be subtracted from the total signal in the time-domain. In addition, he proposed prefiltering the MLS-sequences to obtain a very short free-field impulse-response, so measurements can be made very close to the surface. Another 'impulse-sharpening' technique is developed by Wilms & Heinz [3]. They divided the complex frequency-spectrum of the total sound by the free-field frequency-response and after back-transforming to the time-domain, the reflected sound can be more easily extracted. Furthermore, if the direct sound can be extracted from the original impulse-response, no free-field measurement is necessary (Garai & Cocchi [4]). This however requires larger distances from the sample.

Another way of measuring sound absorption is the use of a model of the sound field in front of a surface. By measuring the sound field in 2 points in front of the surface and the dependency of the reflection coefficient on the sound field, the reflection coefficient can be determined implicitly, or explicitly in the case of an easy model. This was done by Allard & Champoux [5] with a simple image-source model (the so-called 'spherical decoupling' method). Applying MLS-sequences is also advantageous in this technique in order to remove unwanted reflections and to reduce the effects of background noise.

2 - MEASUREMENT METHODS

Three techniques mentioned above have been applied on three material samples and with two different sources in a semi-anechoic room. Preliminary to the material measurements, a series of free-field measurements is done for both sources at a number of distances from the source in the middle of the room.

1. The so called '**subtraction technique**' [2] is examined without prefiltering the MLS-sequences. Further improvements are made. Firstly, since the shape of the free-field impulse-responses seemed to be dependent of the distance to the source, the material measurements were time-shifted to the nearest free-field impulse-response and the necessary amplitude correction was applied. Secondly, the recorded impulse-responses are interpolated in the time-domain by zeropadding in the frequency-domain. This way, the impulse-responses have a smoother appearance and more accurate time shifting is made possible. Both effects made it possible to have a nearly perfect subtraction of the free-field impulse-responses. Additionally time-windows for the free-field- and for the material measurements were chosen equal to obtain a better subtraction.

2. The '**impulse sharpening**' technique has been applied as described in [3]. Parasitic reflections in the material-measurements have been windowed out before complex division by the (equally windowed) free-field impulse-response. No band-pass filter was applied to the material measurements before complex division. Since no phase information on the reflection coefficient was needed, no time-shifting has been applied to the 'sharpened' reflection.

3. In the '**spherical decoupling**' method [5], both microphone impulse-responses are windowed to remove parasitic reflections.

3 - MEASUREMENT PROCEDURE

All measurements were made in a semi-anechoic room. Only normal-incidence measurements are reported here. The following **devices** are used:

- Sound sources: Acoustical driver unit TOA, model TU-50 and JAMO 28 2-way loudspeaker 55W (see figure 1)
- Microphone: 1/2" Condenser Microphone B&k 4130 with preamplifier B&k 2642
- Pc-Soundcard: DAL CardD+
- Amplifier: Realistic MPA 100 (100W)
- MLS-properties: sequence length 371 ms (order 14), sampling frequency 44100 Hz
- Software: Matlab Graphical User Interface in combination with WinMLS-software

Figure 1: Sound sources.

Two **source configurations** have been studied: hung on the ceiling or hung in the middle of a 2m bar, supported on its ends by two heavy tripods. The **microphone** was mounted on a horizontal rod (1-microphone techniques) or mounted in a suspended telescopic microphone-holder (2-microphone technique) which allows to do 2 successive 1-microphone measurements at fixed distances (see figure 2). Four distances are measured: 5, 10, 50 and 100 mm. These allow to measure in 4 frequency ranges. The final absorption spectrum is a weighted combination of the 4 resulting absorption spectra.

Figure 2: Detail of distance probe.

Three **PUR-foam samples** of 2×4 m^2 were measured on the acoustically hard floor. Sample 1 had a thickness of 25 mm and a flow resistivity of 20 kNs/m^4. Samples 2 and 3 had a thickness of respectively 47 and 104 mm with a flow resistivity of 80 kNs/m^4. All samples have a density of 30 kg/m^3.

4 - RESULTS

Measurements have been made on the 3 samples for several source-surface distances (H) and several microphone-surface distances (h). For comparison, measurements in a 40 mm Kundt's tube have also been made. An overview of the obtained results following the 3 methods and using the 2-way loudspeaker, is given in figures 3, 4 and 5 for res. sample 1,2 and 3. The results are displayed for 'optimal' source-microphone-surface distances (see below). For the 2-microphone technique (method 3), h is the microphone-surface distance for the microphone in its lowest position. All applied time-windows had a length of 8 ms.

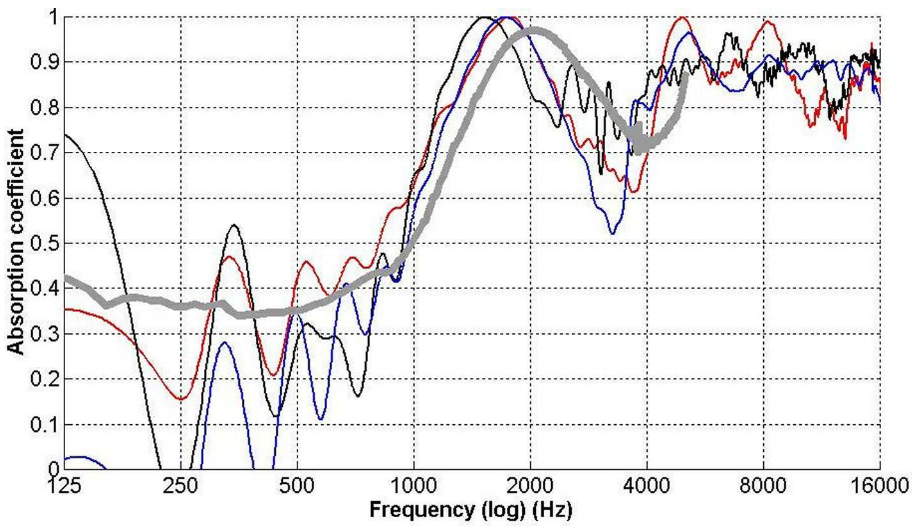

Figure 3: Absorption coefficient for sample 1: (red) method 1 with H=1.270m, h=0.022m; (black) method 2 with H=1.270m, h=0.226m; (blue) method 3 with H=1.231m, h=0.016m; (thick grey) measurement in Kundt's tube.

For sample 1 and 2, the measured absorption curves of all three methods show a frequency shift towards lower frequencies, when compared to the measurements in the impedance tube. This effect is attributed to the friction between the sample and the tube-wall in an impedance tube experiment.

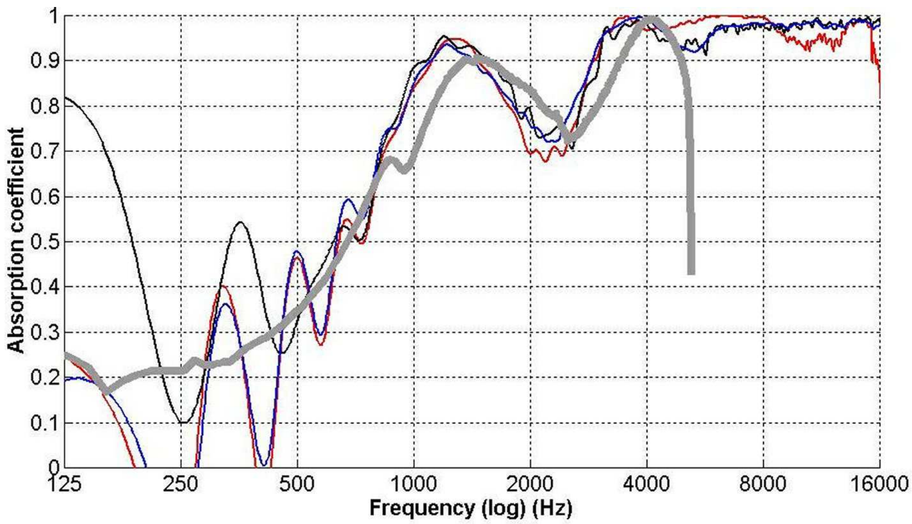

Figure 4: Absorption coefficient for sample 2: (red) method 1 with H=1.241m, h=0.019m; (black) method 2 with H=1.241m, h=0.267m; (blue) method 3 with H=1.208m, h=0.025m; (thick grey) measurement in Kundt's tube.

5 - IMPORTANT PARAMETERS - GUIDELINES

5.1 - Source type

From the comparison of the measurements with both sound sources, it was clear that the source with the flatter **frequency response** is to be preferred. By having shorter free-field impulse-responses, shorter time windows are possible and measurement positions closer to the surface can be chosen, which results in more reliable results due to the better signal to noise ratio (see figure 6 for a comparison of both free-field impulse-responses).

A smaller **source size** is of course an advantage: it allows a better approximation of the spherical wave and less free field measurements will be necessary.

However, both requirements are incompatible and a compromise has to be reached. Possible solutions can be the use of digitally prefiltered MLS-sequences [2] or the use of an equaliser.

The 'spherical decoupling' method seemed to be less sensitive for the type of source since no separation of direct and reflected sound has to be made.

5.2 - Source height

For a good signal-noise ratio and to avoid parasitic reflections from other objects, the source should be placed close to the surface. But the supposition of a spherical sound field needs to be fulfilled. The necessary minimal distance has been found to amount to approximately 2 wavelengths. For normal-incidence measurements, also the secondary source-material-source-reflection can be detected in the impulse-responses and this means an additional restriction to the window-lengths (see figure 7 for an example).

In our measurements, a source-distance of 1.2 m has been found optimal.

5.3 - Microphone height

To have most information about the surface properties and to avoid parasitic reflections from other objects, the microphone has to be positioned close to the surface. Obviously, if the surface is not homogeneous and flat, a certain distance has to be taken in order to obtain global sound absorption properties.

For the '**subtraction**' technique, measurements very close to the surface had the best results. Measurements with the microphone laid on the material sample showed very good agreement with measurements at short distances (typically 2cm) to the surface. This is of course a simple directive for in-situ application, but is only valid for the type of materials as tested.

Distances down to 2 cm from the surface have shown to be possible with the '**impulse sharpening**' technique, even though a time-separation has to be made after complex division. However, in this case the time-window must be very steep and be positioned very carefully. Distances up to 30 cm showed similar results, however larger oscillations occur at low frequencies when measuring at larger distances.

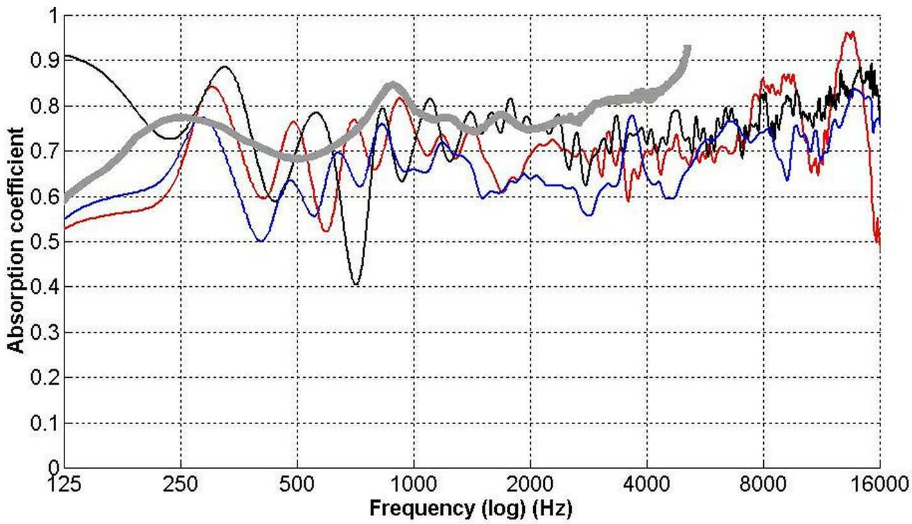

Figure 5: Absorption coefficient for sample 3: (red) method 1 with H=1.190m, h=0.039m; (black) method 2 with H=1.190m, h=0.259m; (blue) method 3 with H=1.091m, h=0.020m; (thick grey) measurement in Kundt's tube.

This is mainly due to the low amplitude of the reflection. Perhaps better results can be obtained for less absorbing materials.
For the '**spherical decoupling**' method, best results are obtained when measured as close to the surface as possible.

5.4 - Influence of source- or microphone stands

Source- or microphone stands can cause parasitic reflections, which cause problems for a correct windowing of the signals. An example of a measurement of the impulse-response with and without source-stands is shown in figure 7. When the source is hung between the tripods, the reflections of these supports become noticeable. The influence of these reflections on the absorption coefficient can be seen in figure 8, where e.g. the 'subtraction' technique is applied on sample 2 with time-windows chosen as in figure 7.

5.5 - Frequency limitations

The free-field amplitude-spectrum of the source must be sufficiently flat to be able to measure in a large frequency-range. The spectrum of the 2-way loudspeaker had a maximum around 1000 Hz, so the measurements are most reliable in that region. At frequencies where the frequency-response of the source is weaker (below 500 Hz or above 10 kHz), large oscillations occur in the absorption spectrum, meaning a high uncertainty due to a too low reflected signal level. Sample-size, angle of incidence, source-height and the inverse of the smallest time-window length, also affect the lower frequency limit. The highest frequency is also influenced by the sampling rate and the irregularities of the surface.

5.6 - The positioning, shape and length of time-windows

Easy control of time-windows is necessary. If possible, the windows must be as smooth as possible to reduce leakage in the frequency-domain. However, for the 'impulse sharpening' technique, very steep windows might be necessary to separate the reflection from the direct sound after complex division when measuring close to the surface. As a compromise, the Tuckey-window is chosen with a control of the steepness of the time-window edges.
The positioning of the windows is not that critical: shifting windows lightly results in small changes in the absorption spectra, provided that no parasitic reflections are added and/or the separation of the direct sound from the reflected sound is clear enough.
The window lengths should be as long as possible to keep the lowest frequency as low as possible and to keep a high frequency-resolution since shorter time-windows lead to a more smoothed absorption-curve (See an example on figures 9 and 10).

6 - FURTHER RESEARCH

We will extend this analysis to several other questions related to the practical application: what is a suitable sample size? What are the special limitations in case of measurement at oblique incidence? What

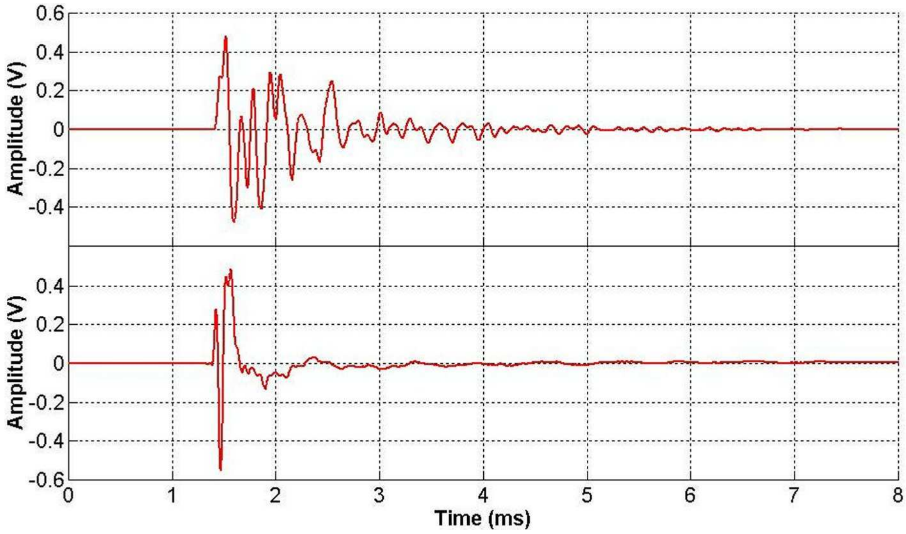

Figure 6: Free-field impulse-responses for the acoustical driver unit (up) and for the 2-way loudspeaker (down).

about the application to other materials, especially inhomogeneous materials and to other absorption mechanisms?

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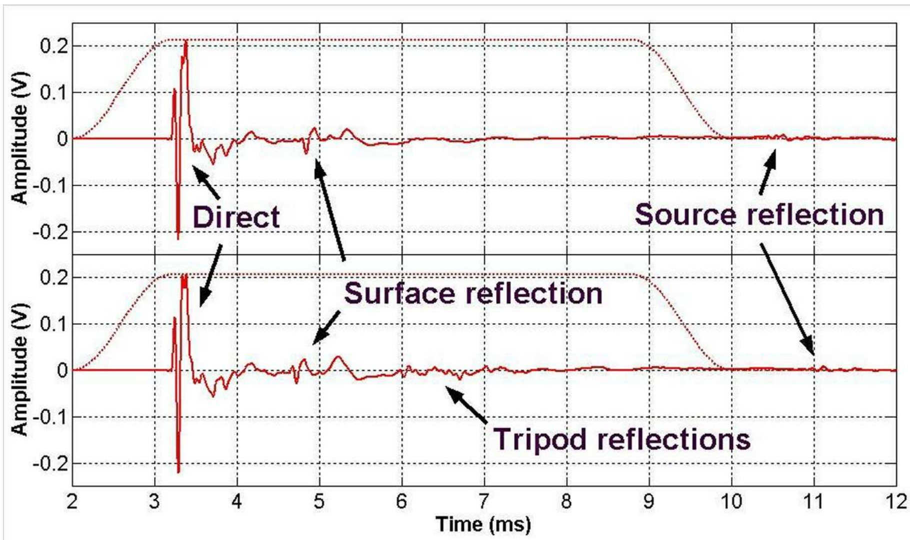

Figure 7: Impulse-responses for sample 2 with and without source-stands; (up) source hung on the ceiling, H=1.241m, h=0.264m; (down) source supported by tripods, H=1.339m, h=0.247m.

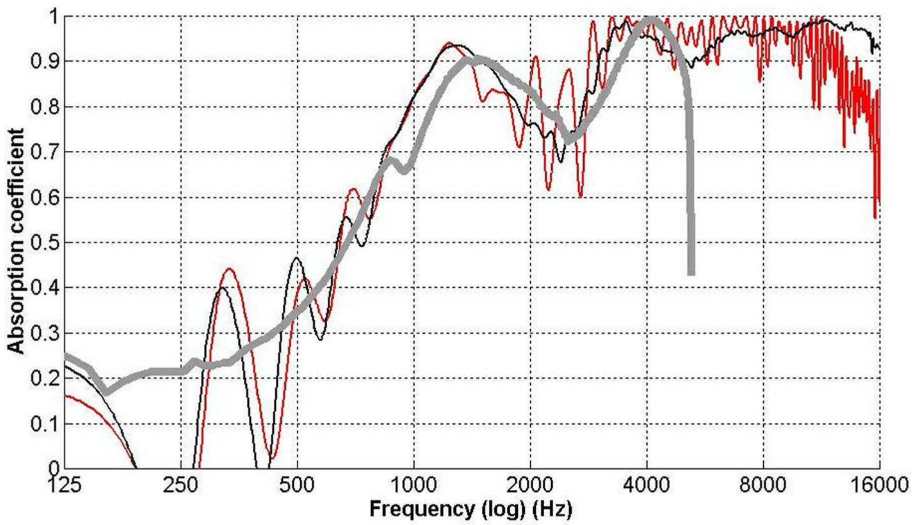

Figure 8: Absorption spectra for sample 2 using method 1 with and without source-stands; (black) source hung on the ceiling, H=1.241m, h=0.006m; (red) source supported by tripods, H=1.339m, h=0.006m; (thick grey) measurement in Kundt's tube.

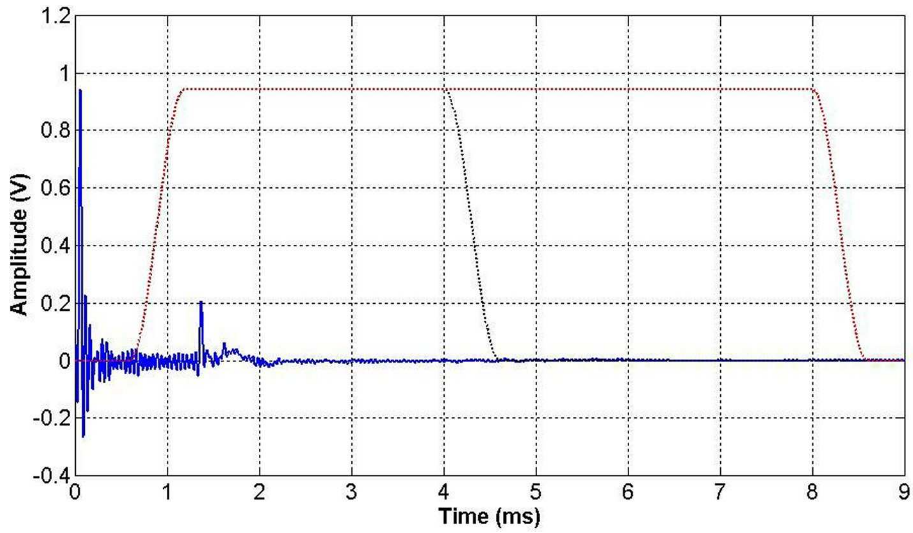

Figure 9: Two different time-windows applied to the impulse-response of sample 2 in method 2 after complex division; H=1.27m, h=0.226m.

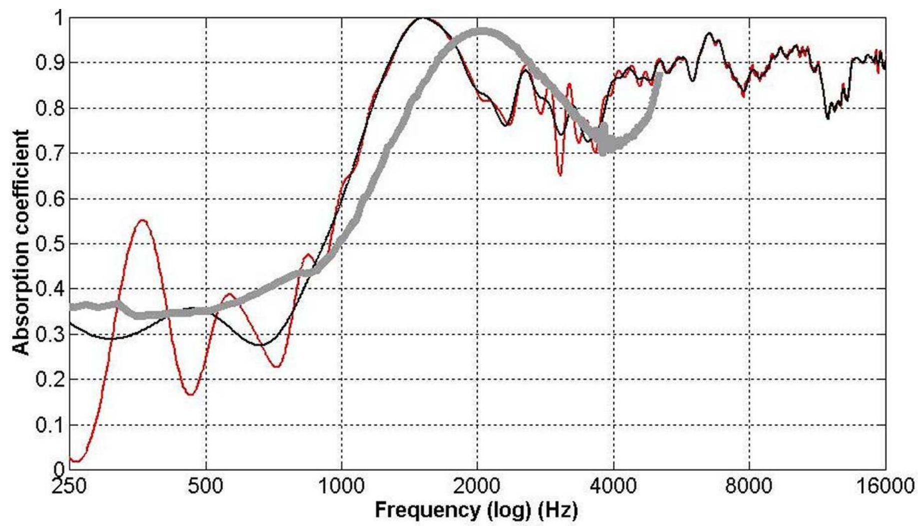

Figure 10: The corresponding absorption spectra when applying a windowlength of 8ms (red) and a windowlength of 4ms (black); (thick grey) measurement in Kundt's tube.