Measurement and theoretical validation of diffraction from a single edge

Tapio Lokki[1] *and Ville Pulkki*[2]

Helsinki University of Technology
[1]Telecommunications Software and Multimedia Laboratory
[2]Laboratory of Acoustics and Audio Signal Processing
Tapio.Lokki@hut.fi

Abstract

In this paper a setup to measure first-order diffraction from one single edge of a plate is presented. In this setup diffractions from other edges of the plate are eliminated by mounting the plate to the corner of an anechoic chamber. The measured data shows that the presented setup can be used to study diffraction from one single edge. In addition, we compare the measured data with the data computed with a theoretical diffraction model. The comparison shows almost perfect match between theoretical and measured responses. Finally, we show how absorption material covering the plate affects to the measured responses.

1. Introduction

It is a well know fact that sound travels around corners and obstacles. This phenomenon is known as diffraction. The theory of diffraction from one single edge is well understood and several analytical solutions have been derived to model diffraction. One of the computational methods for diffraction from a finite length edge has been presented by Svensson et al. [1]. This time-domain model is interesting from room acoustics modeling point of view, since it can be applied in sound field decomposition [2], in conjunction with the image-source method [3, 4].

Even if the theory of edge diffraction is well known, only a few recent papers have shown measured diffraction data [5, 6]. In these papers, the studied geometries are quite complex ones in which great number of diffractions exist and only overall accordance between measurements and modeling results can be seen.

In this paper, we focus our efforts to study first order diffraction from one single edge to see accurately how well the Svensson's algorithm corresponds with the measured data. To be able to measure such single edge diffraction, we developed a measurement concept which minimizes diffractions from other edges of the plate and the higher-order diffractions.

The paper is organized as follows. In Section 2 the measurement setup and utilized equipment are presented. Then, the post processing of measured responses is explained and theoretical computation method is overviewed. In Section 3 the results of measurements are presented with comparison to the theoretical model. Finally, conclusions are drawn in Section 4.

2. Measurements of diffraction from a single edge

The measurement of diffraction from a single edge is not a trivial task. First of all, an anechoic chamber is needed. Eventhough such a room is available it is very hard to isolate only one edge to be measured. If we add an obstacle, e.g. a triangular plate between source and receiver positions, it is difficult to measure diffraction from one single edge since all three edges diffract sound. In addition to three first order diffractions, also higher order diffractions would be seen in measured responses. However, for this study, we needed a measurement setup where diffraction would only occur in a single edge.

Figure 1: *The measurement setup. In reported results, the microphone was positioned under the chipboard plate.*

The attenuation of diffractions from all other edges (than the one under study) was obtained in the following way. A triangular shaped 20 mm thick chipboard was mounted to the corner of an anechoic room, in a way that two of the three edges of the plate were between the absorbing wedges, i.e. inside the walls of the anechoic room, see Fig. 1. The setup should allow to measure diffraction from one edge as diffractions from other edges should be attenuated almost completely. Having only one not-attenuated diffractive edge also yields that no higher-order diffractions should be seen in the measured responses.

The measurement setup consists of a loudspeaker (Genelec 1030A) mounted above the studied edge of the plate and a microphone (B&K 4192) positioned to different positions. The impulse response measurements were performed by applying a swept-sine technique [7].

2.1. Post processing of measurements

We measured the effect of diffraction from one source position to several receiver positions. To see properly the effect of edge

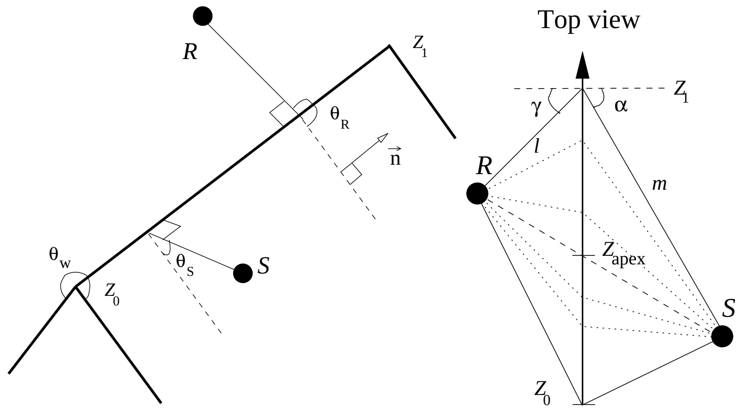

Figure 2: Geometry of a finite wedge. On the right sound paths via edge points Z_0 and Z_1 are indicated by the solid lines, the least-time sound path via the apex point $Z_{\mathtt{apex}}$ is depicted with dashed line and some other sound paths are illustrated with dotted lines.

$$h(t) = -\frac{\nu}{4\pi} \int_{Z_0}^{Z_1} \delta\left(t - \frac{m+l}{c}\right) \frac{\beta_{++} + \beta_{+-} + \beta_{-+} + \beta_{--}}{ml} dZ \tag{1}$$

$$\beta_{\pm\pm} = \frac{\sin[\nu(\pi \pm \theta_{\mathrm{S}} \pm \theta_{\mathrm{R}})]}{\cosh\left(\nu \cosh^{-1} \frac{1+\sin\alpha\sin\gamma}{\cos\alpha\cos\gamma}\right) - \cos[\nu(\pi \pm \theta_{\mathrm{S}} \pm \theta_{\mathrm{R}})]} \tag{2}$$

diffraction, the measured raw data was system compensated. First, an impulse response without the diffractive plate was measured to get the reference response. From this reference, the impulse response of the loudspeaker was windowed with the second half of a Hanning window. Then the measured diffraction responses were deconvolved with the reference response. Finally, the measurement equipment compensated responses were lowpass filtered to remove the high frequency noise which originated from deconvolution.

2.2. Computation of the theoretical response

The applied modeling method for edge diffraction is the computational method presented by Svensson et al. [1]. It allows to compute a theoretical response from a rigid edge of a finite length. In this method a diffractive edge is divided into small fragments through which sound rays travel from a source to a receiver. The impulse response $h(t)$ of an edge is a sum of all these rays, and it can be computed with Equations (1) and (2). The variables can be found in Fig. 2 where a finite wedge is illustrated. In addition, c is the speed of sound, $\nu = \pi/\theta_{\mathrm{w}}$ is the wedge index, m is the "source-to-edge point" distance, and l is the "edge point-to-receiver" distance. The integration range is between the two end points of a finite edge.

3. Results and discussion

We measured impulse responses from several receiver positions. However, in this paper, the data from only one receiver position is presented. The positions of the loudspeaker and the microphone are illustrated in Fig. 3.

First, the applicability of presented measurement setup is considered. Figure 4 illustrates how well other edges than the one under study are attenuated. It can be seen that in the measured response no peaks occur around 2 ms timestamp where

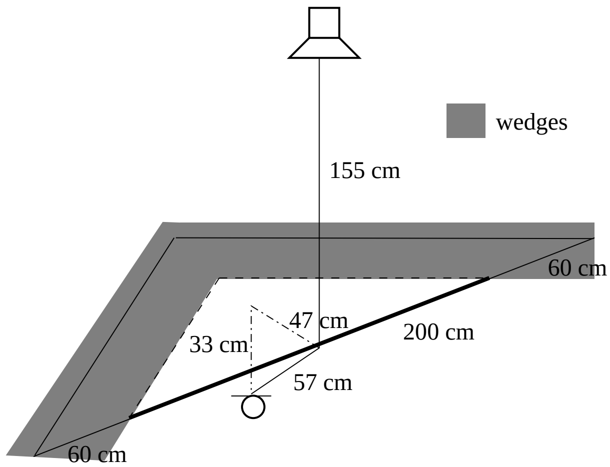

Figure 3: *The positions of the loudspeaker and the measurement microphone. Note that board occludes the sound source in the measurement position.*

the diffractions from two other edges should be according to the simulated response. Figure 4 confirms our assumption that the measurement setup attenuates diffractions from edges inside the walls of the anechoic chamber, since in that case sound has to travel through several absorptive wedges, see illustration in Fig. 5.

It can also be argued that the diffraction from the considered edge can be isolated from other diffractions by windowing in time. This is indeed possible for the presented response in Fig. 4, but not possible with all microphone positions. In some cases, where distracting other diffractions overlap with the studied one, the windowing in time cannot be performed.

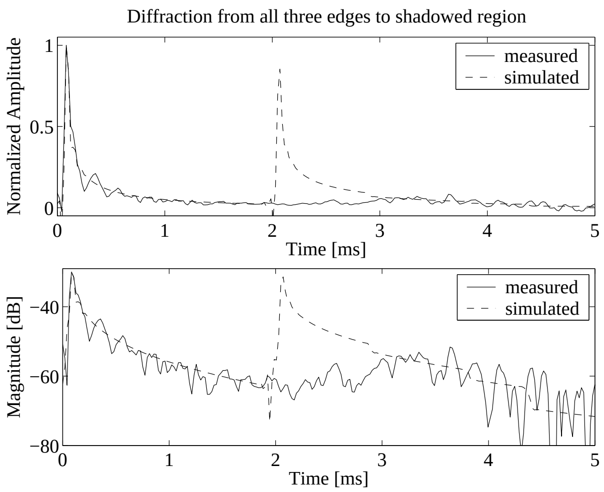

Figure 4: *The comparison of simulated and measured responses. Two diffractions, occuring at the same time around 2 ms due to the symmetric measurement setup, are attenuated in the measured response.*

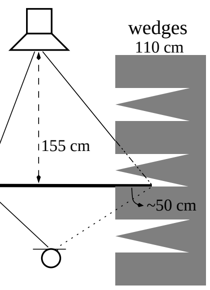

Figure 5: *The schematic drawing of the setup for measuring diffraction from a single edge. Diffraction from the edge between the mineral wool wedges is attenuated since the sound has to travel through several absorptive wedges.*

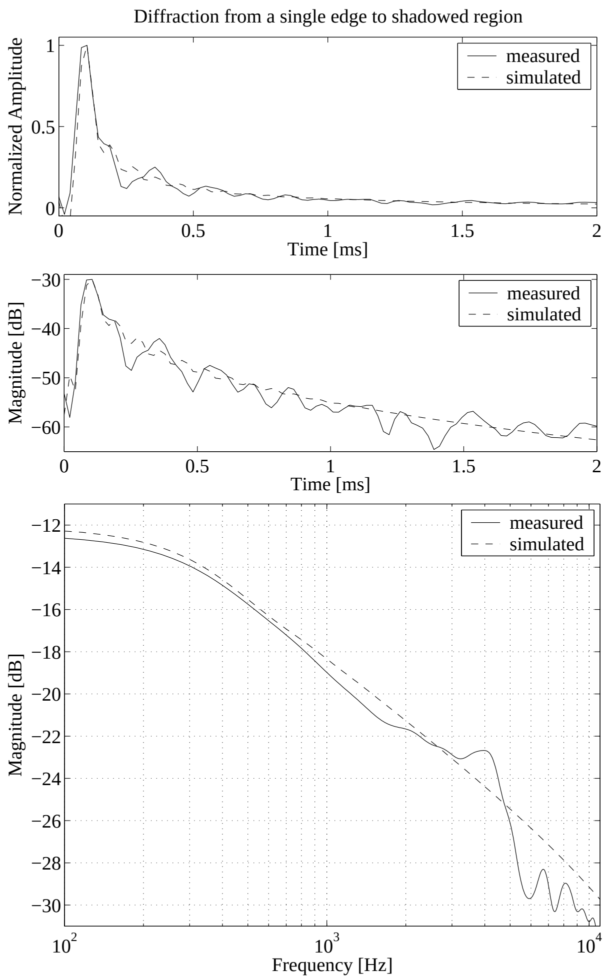

Figure 6: *The measured and simulated diffractions from a single edge presented both in the time and in the frequency domains. The measurement setup is illustrated in Fig. 3.*

3.1. Results from hard plate measurements

The system compensated response from the measured edge is compared to the simulated response both in the time and in the frequency domains. The comparison is presented in Fig. 6 and it can be seen that generally the measured response matches well with the simulated one. However, in the time domain, the measured response has little bit more fluctuation than the simulated response. In the frequency domain, the magnitude responses are within 1 dB up to 3 kHz. At higher frequencies the measured response have faint oscillation.

The measured diffraction from the edge matches well to the theoretical response which has been proven to be an exact mathematical solution for diffraction from a rigid finite edge [1]. The ± 2 dB difference between simulated and measured responses above 3 kHz might come from higher order diffractions. Due to the fact that the plate was 20 mm thick, the plate indeed contains two diffractive sharp wedges. At low frequencies, these two sharp wedges can be considered as one edge since the distance between them is small compared to the wavelength. However, at high frequencies, above 3 kHz, the wavelength is so short that higher order diffraction might be seen in measured response as faint oscillation.

3.2. Results from measurements with the covered plate

In addition to the hard plate measurements, we measured the same chipboard plate covered with 50 mm mineral wool. There are several ways to cover the plate with the mineral wool. In Fig. 7 we compare measured results from empty surface (hard) with the case of covered plate (mineral wool on top of the plate, as in Fig. 1). In addition, in Fig. 7 results from measurement, where mineral wool was on top of the plate but installed 10 cm apart from the edge, are seen. Figures show that if the wool is more that 10 cm apart from the edge, the effect of the absorbent is negligible. However, in the case where mineral wool covers the plate totally the measured diffraction is attenuated approximately 2 dB between 1.8 and 5 kHz. At higher frequencies the attenuation is almost 5 dB.

The last comparison is made between the cases in which mineral wool is mounted both under and above of the plate. The measured responses are shown in Fig. 8. The effect of mineral wool on top of the plate is the same as in the previous case. When the absorbent is mounted under the plate, the measured absorption is higher. The material absorbs sound approximately 3 dB, starting already around 600 Hz. When absorbing wool is on both side of the plate the cumulative absorption on both side

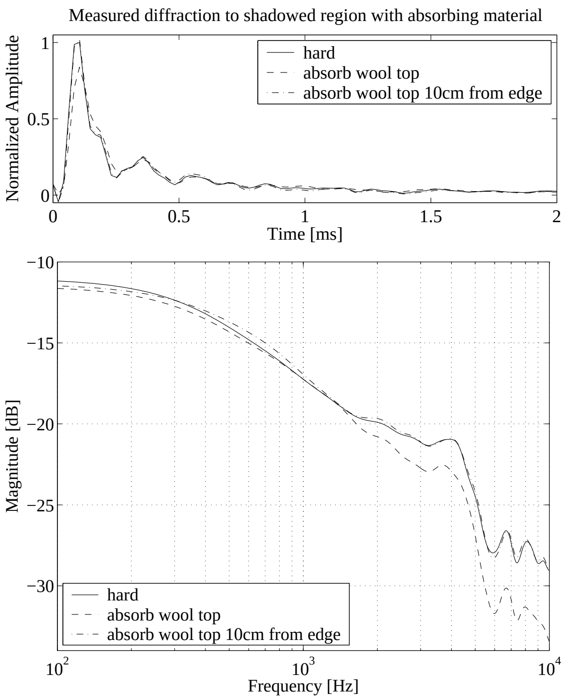

Figure 7: *The measured diffraction from a single edge with and without mineral wool on top of the plate.*

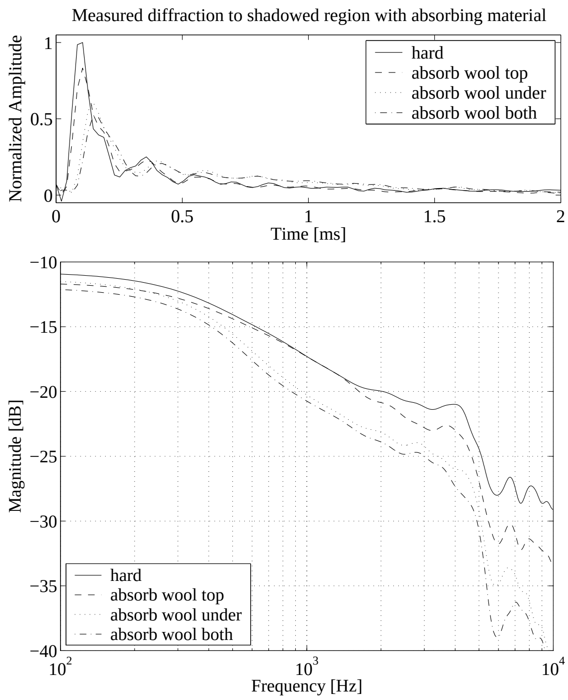

Figure 8: *The measured diffraction from a single edge with and without mineral wool under and on top of the plate.*

is seen.

The effect of mineral wool under and on top of the plate is clearly seen in Figs. 7 and 8. The absorption effect is obvious, but the reason why absorption starts around 1.7 kHz (wool on top) and around 500 Hz (wool under) is not so obvious. Naturally, it has to be related somehow to the wavelength of sound and how long distance sound waves travel inside the mineral wool. In "absorbent on top" case, sound is coming directly above the edge and sound travels approximately 5 cm inside the mineral wool. At 1.7 kHz the wavelength of sound is 20 cm which is exactly four times the thickness of the absorptive material. In absorbent under the plate case, the microphone is placed so that sound travels inside the wool almost 10 cm. The 40 cm wavelength corresponds about 850 Hz which is not so far from 600 Hz where absorption starts. As a conclusion it can be stated that in our setup the mineral wool acts as sound insulation material through which sound has to pass. With the measured material, it seems that it absorbs sound when the absorption material is thicker than one fourth of the wavelength of sound.

4. Conclusions

In this paper we have introduced a setup to measure edge diffraction. The presented measurement setup allows us to study first-order diffraction from one single edge. In addition, measurement results were compared to simulated results and a good accordance was found between them. In addition to hard plate measurements, diffraction was measured in several cases when the plate was covered with absorbing material. The results of this study can be applied in development of room acoustics modeling methods.

5. Acknowledgments

Ville Pulkki has received funding from the Academy of Finland (#101339).

6. References

[1] U. Svensson, R. Fred, and J. Vanderkooy, "Analytic secondary source model of edge diffraction impulse responses," *J. Acoust. Soc. Am.*, vol. 106, no. 5, pp. 2331–2344, 1999.

[2] U. Svensson and U. Kristiansen, "Computational modeling and simulation of acoustic spaces," in *AES 22nd Int. Conf. on Virtual, Synthetic and Entertainment Audio*, Espoo, Finland, June 15-17 2002, pp. 11–30.

[3] J. B. Allen and D. A. Berkley, "Image method for efficiently simulating small-room acoustics," *J. Acoust. Soc. Am.*, vol. 65, no. 4, pp. 943–950, 1979.

[4] J. Borish, "Extension of the image model to arbitrary polyhedra," *J. Acoust. Soc. Am.*, vol. 75, no. 6, pp. 1827–1836, 1984.

[5] R. Torres, U. Svensson, and M. Kleiner, "Computation of edge diffraction for more accurate room acoustics auralization," *J. Acoust. Soc. Am.*, vol. 109, no. 2, pp. 600–610, 2001.

[6] N. Tsingos, I. Carlbom, G. Elko, T. Funkhouser, and R. Kubli, "Validation of acoustical simulations in the "Bell Labs Box"," *IEEE Computer Graphics and Applications*, vol. 22, no. 4, pp. 28–37, July/Aug. 2002.

[7] A. Farina, "Simultaneous measurement of impulse response and distortion with a swept-sine technique," in *the 108th Audio Engineering Society (AES) Convention*, Paris, France, Feb. 19-22 2000, preprint no. 5093.