

Visualizing diffraction of a loudspeaker enclosure

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Abstract

With the image-source method the room acoustics can be visualized by plotting image sources around the listener, which yields an intuitive illustration of acoustics. Lately, the image-source method has been extended to also include edge diffraction. In this paper, a visualization method for diffraction phenomenon is presented, which illustrates how diffraction behaves in different conditions. As an example, first- and second-order diffraction in loudspeaker enclosure is visualized.

1 Introduction

Visualization of sound field is useful in design of acoustics and in educational purposes. For visualization, the sound field has to be either measured or modeled. While measurement of 3D sound fields is in many cases impracticable, modeling of an acoustic space is an attractive approach. Acoustics can be modeled with different techniques. In some cases, wave equation can be solved exactly or it can be approximated numerically using finite or boundary element methods, an overview can be found in [1]. These methods simulate a 3D sound field as a function of time inside a modeled space. Direct visualization of a 3D sound field is awkward with standard 2D visual displays. Furthermore, it does not give a priori knowledge of contributions of different types of interactions between sound waves and room geometry, such as specular reflections or edge diffractions.

In many room acoustic modeling methods sound waves are modeled with sound rays. Thus, sound is considered to propagate as rays and the wave phenomena of sound are neglected. Such assumptions give an exact solution for wave equation only in a rectangular room with rigid surfaces [2]. In this solution reflections from

surfaces are represented with mirror image sources. The concept of image sources (IS) is also fruitful in visualization of acoustics. By illustrating the image sources around the studied geometry the spatial and temporal distribution of reflections is clearly seen.

The image-source method has been also applied to complex geometries [3], though neglecting edge diffraction. Recently, edge diffraction has been included by Svensson et al. [4]. This solution is exact for geometries that include rigid surfaces with any geometry. In Svensson's solution a diffractive edge is divided into small elements through which sound rays travel from a source to a receiver. The radiation characteristics of each element is calculated, and the resulting impulse response in receiver position is a sum of unit impulses radiated from all these elements. While the diffraction has now been added to the image-source method, it would be useful to be able to visualize sound from diffractive edges. In this paper a visualization method for edge diffraction is presented.

2 Edge diffraction with the image-source method

This work has been conducted as an extension to DIVA (Digital Interactive Virtual Acoustics) project [5, 6]. Edge diffraction was implemented recently to the image-source method included in DIVA [7]. In the implementation, edge diffraction is treated as a new form to create image sources. Each image source can contain any number of reflections, and maximally two diffractions, in any order. Image sources are named differently based on whether they contain diffracted components or not. A mirror image source (MIS) denotes an image source that includes only specular reflections. Correspondingly, an edge image source (EIS) denotes an image source with at least one diffraction and any number of specular reflections. The order of an image source is the order of reflections added with the order of diffractions.

Image sources may be formed by any permutations of reflections from different surfaces and diffractions from different edges. However, in complex geometries most of them are not visible to receiver, i.e., there is at least one obstacle on propagation path of sound. Visibility of a MIS is tested by computing the propagation path and checking that there are no obstacles on the path, and by checking that a mirrored image source is visible through the last reflection surface. With edge image sources visibility check should be done to all points of the edge, since it may be partly visible. In practice an edge can be divided into a finite number of fractions, the visibility is checked for all of them.

3 Visualization of edge image sources

In visualization of a MIS the listener-relative direction of it corresponds to the direction from where the sound arrives to the listener. In addition, the distance between the listener and MIS corresponds to the length of total sound propagation path. These visualization principles are now extended also for edge diffraction.

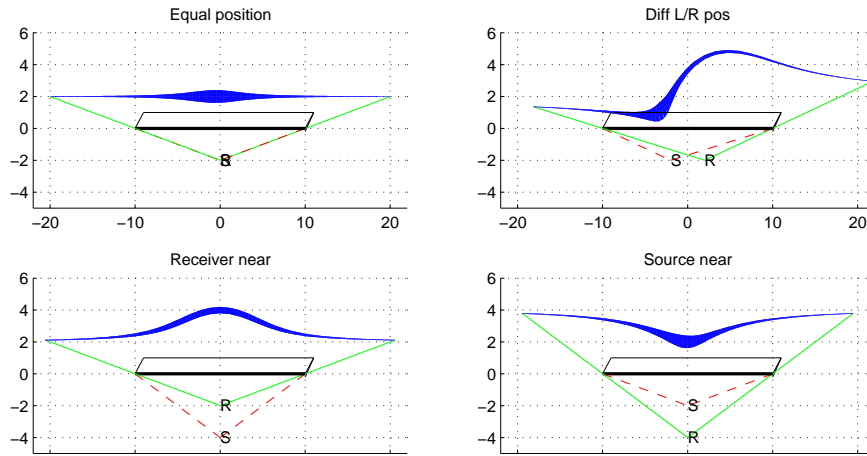


Figure 1: Visualized first-order edge image sources. A thick line (of a rigid plate) denotes a diffracting edge, the curve is the visualization of an edge image source and R and S receiver and source, respectively.

3.1 First-order diffraction

When a single diffractive edge is presented in sound propagation path, an image source can no longer be visualized as a point source, rather it is a line source. A line source can be considered to consist of an infinite number of point sources that are arranged on a line. Each point source is then visualized as a MIS. This leads to quite a simple procedure to visualize an EIS. The edge corresponding to EIS is divided into small fractions. The receiver-relative direction and propagation path length are computed for each fraction, which yields position information for each fraction. The EIS is visualized by connecting adjacent fractions with a line. Furthermore, the amplitude of each fraction in a line can be visualized as thickness or/and color of it. This is illustrated in Fig. 1 for a first-order EIS occurring in one edge of a plane.

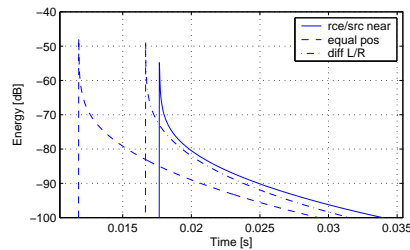


Figure 2: Energy-time curves in receiver positions shown in Fig. 1

The energy-time curves of four cases in Fig. 1 are presented in Fig. 2. The differences between cases are small. The length of propagation path affects to the starting point of response, which can be directly seen as shortest distance between receiver and visualized image source. The farther the image source is from receiver, that later the response is present. An interesting fact is that the response is identical in *receiver near* and *source near* cases, although the visualization is not. The identical responses are due to reciprocity, and different visualizations are due to fact that the sound arrives to the receiver from wider angle when it is near the edge. If a response was measured with a directive microphone, e.g., a dummy head, the responses would be different, which motivates different visualization for reciprocal cases this time.

3.2 Second-order diffraction

In second-order diffraction there exists two edges within a propagation path of sound. Each part of the second edge in propagation path receives a response from each part of first edge. At different positions of the second edge, the first-order response has a variable temporal length due to geometry. The response that a small fraction of second edge emits has naturally the same temporal length as the response coming from first edge to that point has. If such an image source is replaced with point sources, the sources should be arranged in a two-dimensional fashion to be able to also present temporal length of each image source part. While with first-order diffraction an EIS appeared as a curved line in space, second-order diffraction resembles a flag that points away from the listener. The surface can be colored similarly than first-order edge image sources. In the following section the proposed visualization method is illustrated with a case of a loudspeaker enclosure.

4 Visualizing diffraction in a loudspeaker enclosure

Sound wave emitted by a loudspeaker element is diffracted from edges of the loudspeaker enclosure. In our example, shown in Fig. 3, the emitting element, i.e., the sound source S is in upper left corner of the enclosure, and the receiver R is one meter in front of the loudspeaker. Edges are numbered from one to four, and edge image sources are denoted as EIS $x[y]$, where x and (optional) y denote the edge(s) within sound propagation path. Let us consider first the first-order edge image source EIS 4 and the second-order edge image source EIS 1.4. They are shown in Fig. 3. EIS 4 is a curved line, as explained before. EIS 1.4 is a surface, since each point on edge 4 receives sound from each point of edge 1. This extends the line source to two-dimensional surface source. The absolute value of amplitude of each point on surface is denoted with grayscale, in color presentations positive can be mapped to shades of red, and negative to blue correspondingly. The color scale used in visualizations throughout this paper is presented in rightmost part of Fig. 3.

As could be expected, EIS 1.4 starts in time just after the last part of EIS 4. This is obvious, since the last part of first-order diffraction occurs in corner between

edges 1 and 4, where second-order diffraction begins from upmost part of edge 1 to rightmost part of edge 4. The length of the “flag” of EIS 1.4 varies with left-right position of edge 4. This can be explained by examining the temporal length of edge 1 response to each point of edge 4. From upmost part of edge 1 the distance to *rightmost* part of edge 4 is zero, while the corresponding distance from lowest part is the length of edge 1. Similarly, from upmost part of edge 1 the distance to *leftmost* part of edge 4 is the length of edge 4, and corresponding distance from lowest part is the diagonal of front plate. Thus, in leftmost part the distance varies less, which makes the temporal response shorter there.

The method can be naturally applied to a more complicated case. In Fig. 4 all first- and second-order edge image sources are shown that occur in edge 4. Three second-order edge image sources are present, EIS 1.4, EIS 2.4, and EIS 3.4. The surfaces of these edge sources have been summed to form a single surface that presents the sound wave reaching from edge 4 caused by first- and second-order diffraction. The energy-time curve of produced impulse response is shown in Fig. 5. The same loudspeaker enclosure is studied in Fig. 6 where EISs for all edges are shown. The illustration shows that diffraction occurring in other edges is similar to diffraction in edge 4. The length of edge and position of source and receiver respectively affect slightly the shapes of visualized edge image sources. Corresponding energy-time curve is shown in Fig. 7.

The last example shows sound wave behaviour when direct sound has been shadowed. In Fig. 8 the first-order diffraction of edge 2 has a very sharp peak in position that corresponds to shortest wave propagation path, which is clearly seen in energy-time curve presented in Fig. 7. Second-order diffractions have so low levels that they can be hardly seen with 80 dB scale. In Fig. 9, only second-order diffraction is illustrated, where details of it can be seen. A strong stripe is present in second-order edge image sources. This seems to be an illustration of the shortest wave propagation path that includes following components: [source] - [each point of edges 1, 3, or 4] - [a point of edge 2] - [receiver]. It seems that in this case second-order diffraction favors the shortest path more than, e.g., in case of Fig. 6.

5 Conclusion

A method to visualize edge diffraction in the image-source method is introduced. First-order edge diffraction is presented as curved line sources, and second-order edge diffraction as surface sources. The visualizations are computed in order that the listener-relative direction and distance correspond to the direction from which the sound arrives to a listener, and the length of propagation path, respectively. The amplitude of diffraction is presented with line thickness and/or with color. As an example, visualizations of diffractions from loudspeaker edges are shown. Visualizations show intuitively the behavior of diffraction in various cases.

6 Acknowledgment

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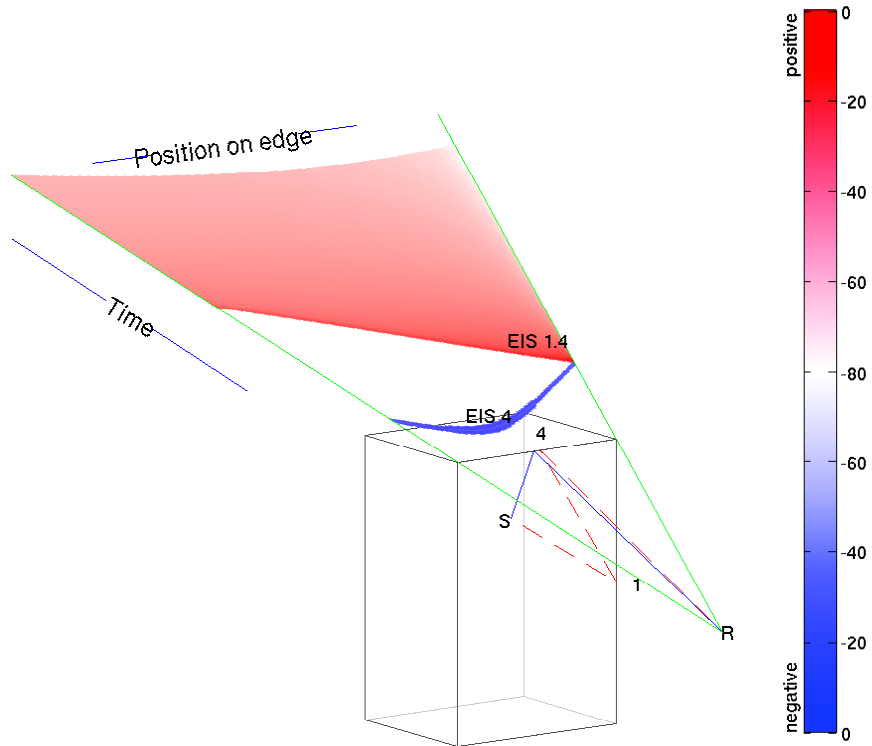


Figure 3: Left: Diffraction caused by two propagation paths. For more clear visualization the amplitude of EIS 1.4 has been amplified 40 dB. Right: The color scale [dB] used in visualizations in this paper. Unfortunately, positive and negative values map to same values in grayscale.

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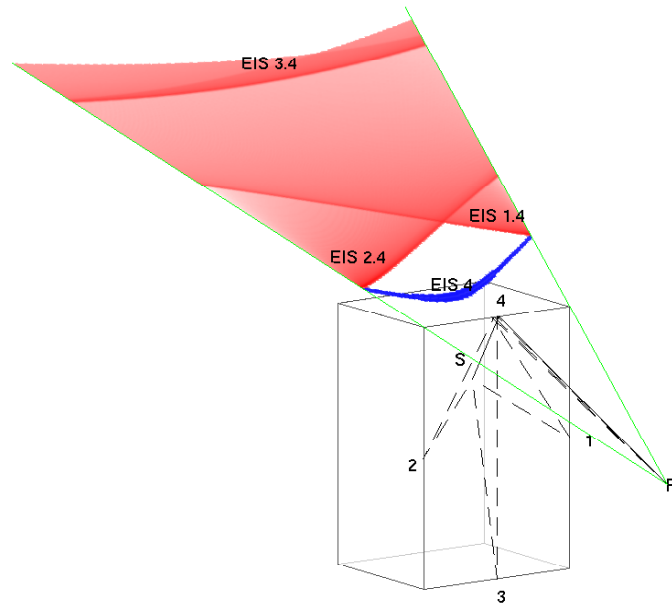


Figure 4: All first- and second-order diffraction components from edge 4. Amplitude of second-order diffraction has been magnified 20 dB.

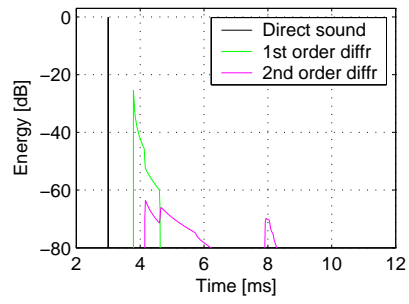


Figure 5: Energy-time curve of Fig. 4

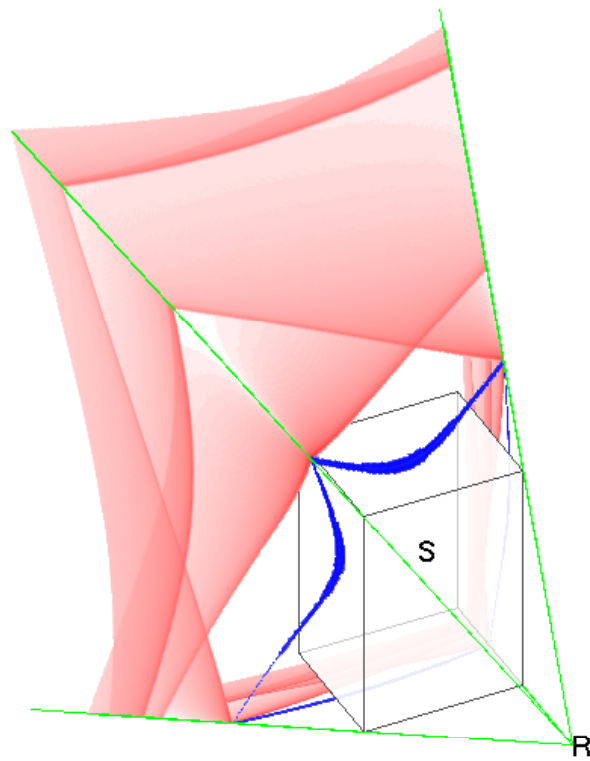


Figure 6: Illustration of first- and second-order diffraction in a loudspeaker enclosure. The amplitude of second-order diffraction has been magnified 20 dB.

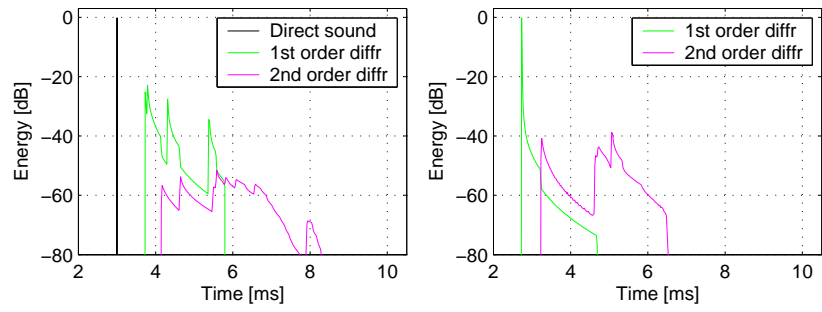


Figure 7: Left: Energy-time curve of Fig. 6. Right: Energy-time curve of Fig. 8

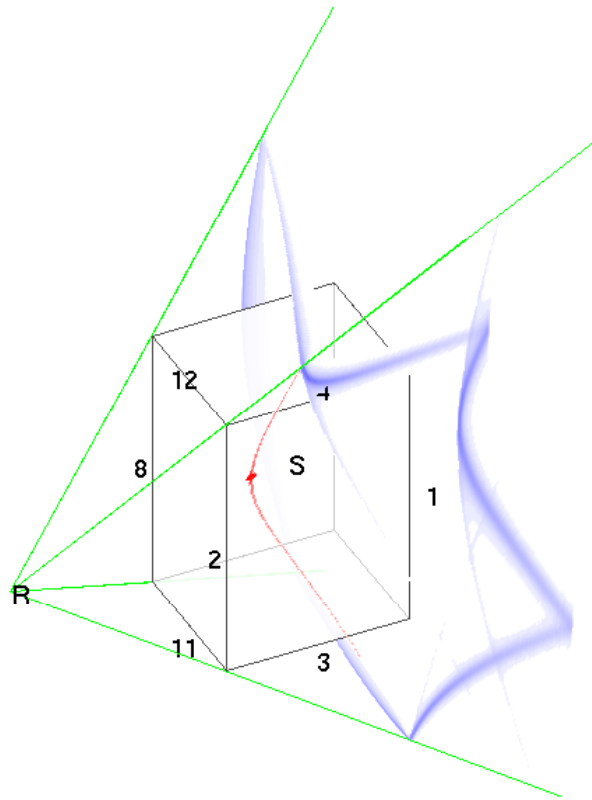


Figure 8: As Fig. 6, but receiver being shadowed in 95° direction. The amplitude of second-order diffraction has not been magnified.

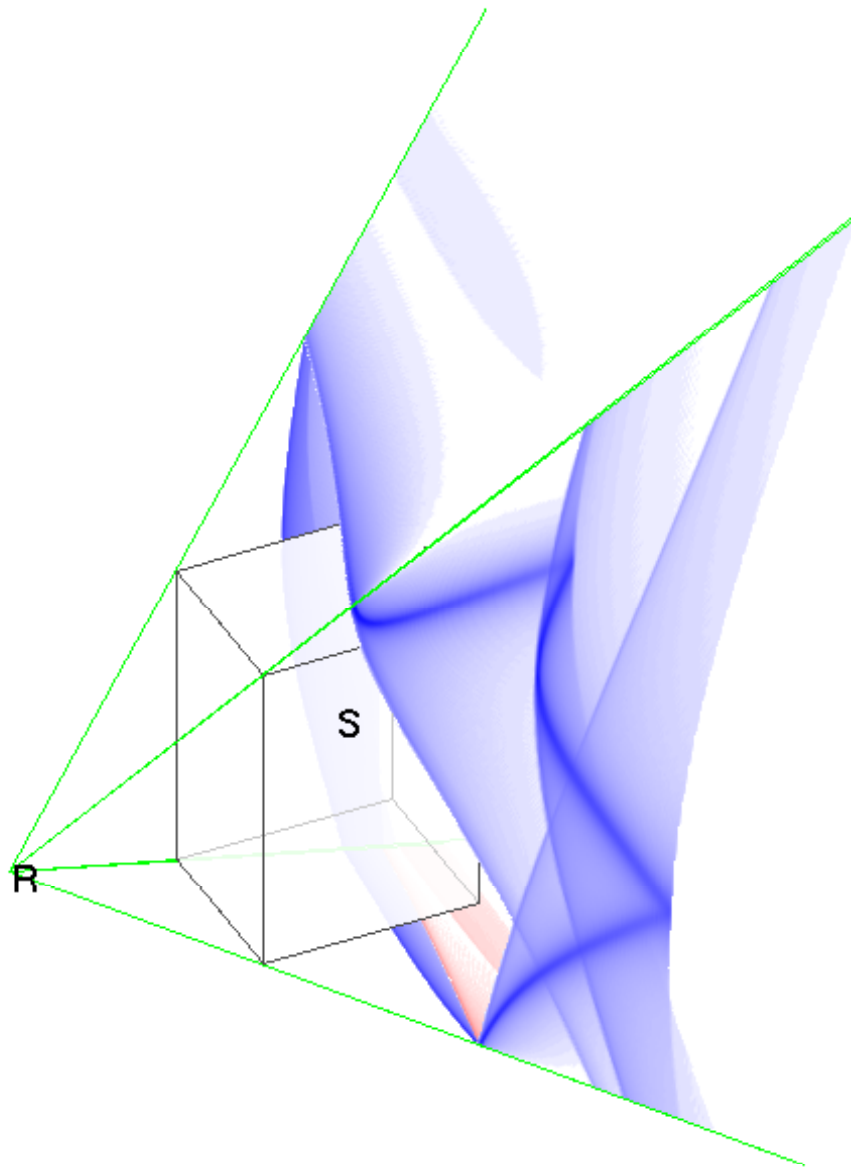


Figure 9: As Fig. 8, but with only second-order diffraction.