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Scattered Responses From Suspended Reflector Panels With Rounded Edges

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SCATTERED RESPONSES FROM SUSPENDED REFLECTOR PANELS WITH ROUNDED EDGES

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ABSTRACT

Sound reflections from most finite surfaces, such as overhead reflector panels, include a component known as edge diffraction. Edge diffraction is the scattered energy required to maintain a continuous sound field despite the discontinuity in acoustical impedance presented by the scatterer. Edge diffraction can interfere with primary scattered energy to produce comb filtering at receiver locations. Several decades ago, the effect of changing the edge profile of loudspeaker boxes was investigated with the goal of producing a smoother frequency response. By rounding the edges of loudspeaker boxes, the edge diffraction could be decreased noticeably [H. F. Olson, J. Aud. Eng. Soc. **17** (1), 22-29 (1969)]. In the current study, boundary element methods are used to study the results of rounding the edges of suspended reflector panels with the same intent of diminishing the boundary wave to achieve a smoother response across the audience area. Specific attention is given to the spatial range and frequency range over which this effect can be achieved.

INTRODUCTION AND BACKGROUND

This paper investigates the simulated responses of reflector panels with convex edges. The convex edges are designed to smooth the scattered response from the reflector panel. The background for this investigation comes from investigations of direct radiator loudspeakers.

The diffracted wave from direct radiator loudspeakers

The effect of sound diffracted from the edge of a finite baffle has been well documented. When a source is placed in a finite baffle, secondary sources appear at the edge of the baffle where the sound wave is diffracted. The interference between the direct energy and the energy diffracted from the edge creates fluctuations in the total sound field, as shown in Figure 1 (after Beranek [1]). The frequencies at which interferences occur can be calculated based on travel time from the source in the middle of the baffle and from the edge.

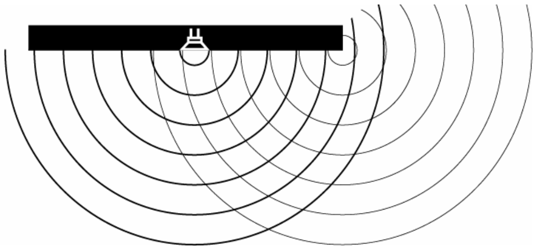

Figure 1.- Diffracted wave from the edge of a baffle (after Beranek [1]).

A comprehensive measurement study was undertaken by Olson [2] in which the shape of direct radiator loudspeaker enclosures was varied with the goal of reducing the strength of the diffracted wave. With a diminished diffracted wave, or boundary wave, the response from the radiator is much smoother because it is not subject to the interferences between the direct and diffracted energy. Olson found that a spherical loudspeaker enclosure produced no boundary wave due to the absence of sharp edges or discontinuities.

Reflector panels

The response from a reflector panel is comparable to the response from a source in a finite baffle. Reflector panel responses are also affected by comb filtering between the primary scattered energy and the diffracted energy from the panel edge.

An examination of curved reflecting surfaces was undertaken by Rindel [3]. The focus of this investigation was the change in reflected level due to the curvature of a surface. The change in reflected level is the level reflected by the reflector of interest normalized to the level reflected by an infinitely large reflector. According to his geometric approach, Rindel found that the change in reflected level could be expressed as follows:

$$\Delta L = -10 \quad \log \quad \left| 1 + \frac{a^*}{R\cos\theta} \right| \qquad \text{(Eq. 1)}$$

$$a^* = \frac{2 * a_1 * a_2}{a_1 + a_2} \qquad \text{(Eq. 2)}$$

where R is the radius of curvature, θ is the angle of incidence with respect to the surface normal, a_1 is the distance from the source to the reflector, and a_2 is the distance from the reflector to the receiver.

EXPERIMENTAL PROCEDURE

The reflector panels are simulated using a 2-D direct boundary element method (BEM) in Sysnoise Rev. 5.6. All panels are meshed in I-DEAS 10 NX Series with a density of at least 6 elements per wavelength. A typical source and receiver distance of 15 meters is chosen to represent the typical placement of reflector panels in concert halls. A plane wave source is used because of the far source-receiver distance. The surface of each reflector panel is considered rigid and assigned infinite impedance.

Three separate source-receiver configurations are investigated (Figure 2). Each configuration corresponds to a particular source receiver pair in a concert hall. In configuration (i), the sound energy is normally incident, and the receiver is within the specular reflection zone. This corresponds to the case of a performer using a reflector panel to monitor his own performance. In configuration (ii), the sound energy is incident at 45 degrees, and the receiver is within the specular reflection zone. This corresponds to the case when a reflector panel normal to the floor is located between two musicians on opposite sides of the stage, or between an onstage source and an audience member. In configuration (iii), the sound energy is normally incident on the reflector panel, but the receiver is outside of the specular reflection zone. This corresponds to the case when a reflector panel is located directly above a performer, but the receiver is outside the specular reflection zone.

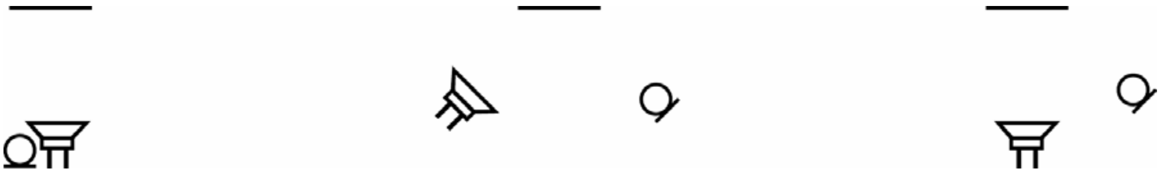

Figure 2.- Geometry of configurations (i), (ii), and (iii)

FIRST STUDY

For the first study, three types of panels are investigated under the above three configurations: a flat reflector (F), a circle (S), and a square reflector with convex edges (CR) (Figure 3). Since the investigation is 2-D, each panel is simulated in place of the reflector in Figure 2 with the orientation shown in Figure 3.

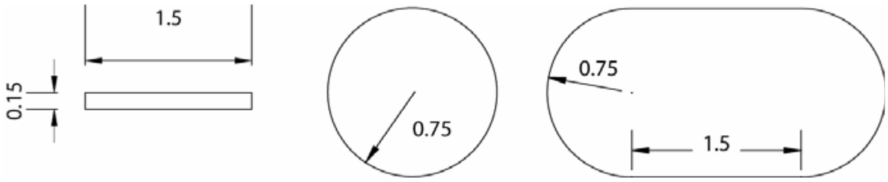

Figure 3.- Reflectors investigated in first study a) F b) S, and c) CR. Dimensions are in meters.

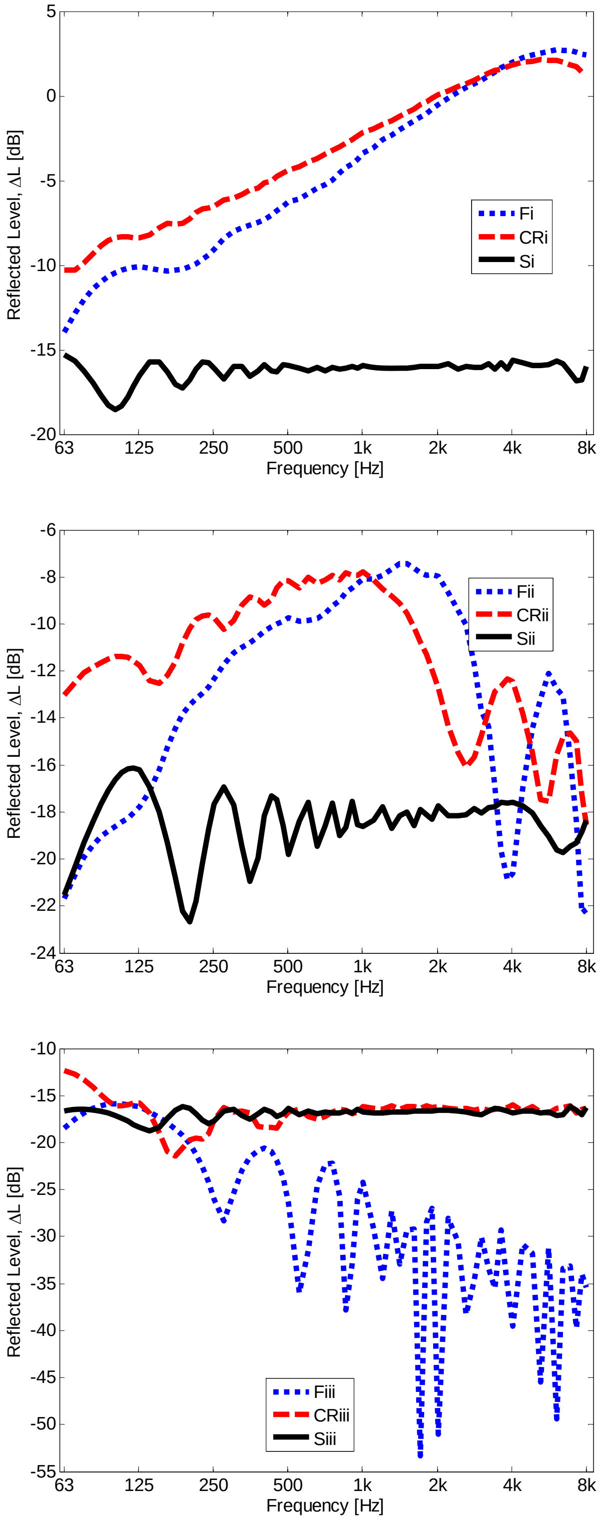

Figure 4.- Responses from a) configuration (i), b) configuration (ii), c) configuration (iii)

Figure 4 shows the BEM results. With the exception of a low frequency ripple, the exclusively round reflector (S) response varies little with frequency for all configurations (i), (ii), and (iii). The change in level due to curvature predicted by equation 1 between the flat panel, F(i), and the curved panel, S(i), is 13 dB. If the response in Figure 4[a] were extended to a higher frequency range where geometrical acoustics is valid, this prediction is expected to be met. In configuration (ii), the 15 dB change in level between (F) and (S) predicted by equation 1 is not met anywhere in this frequency range. The maximum change in level observed at mid frequencies is 10 dB. For configuration (iii), equation 1 is invalid because the receiver is outside of the geometrical reflection zone for (F).

No comb filter is present at higher frequencies for the flat panel (S) in configuration (i). The arrival of the boundary wave is not expected until 9125 Hz and is therefore not shown in this frequency range. A comb filter can be seen in configuration (ii) of 3830 Hz, which corresponds to a difference in travel distance of .09 m. The predicted frequency of the comb filter in this configuration is 3715 Hz. For configuration (iii), the flat panel response shows a comb filter of 277 Hz. The predicted comb filter for this configuration is 324 Hz.

The rounded panel (CR) behaves almost identically to the flat panel for configuration (i). In configuration (ii), the rounded panel also behaves similar to the flat panel, but the fine structure is different. In configuration (iii), the curved panel behaves much more like the circular panel. This corresponds to a comment from Beranek [4] that the sharp drop off of reflected energy outside the specular reflection zone can be avoided if panel edges are curved.

Discussion of low- and mid-frequency ripple

The low- and mid-frequency ripple is present in all curves of Figure 4, but it is most easily observed in the responses from S. This ripple can be understood in terms of the reflection coefficient of sound normally incident on the curved surface of a rigid, infinite cylinder. The scattered pressure is proportional to the reflection coefficient. Ripples occur in the low frequency response from a cylinder at locations where the magnitude of the reflection coefficient is at a minimum.

SECOND STUDY

Reflective panels in the shape of (CR) made of solid material would be both prohibitively expensive and heavy. More practical would be a reflector with the shape of (CR) made of a thin (but rigid) panel (Figure 5).

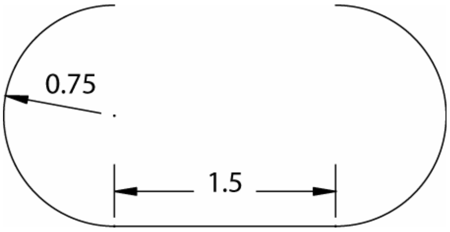

Figure 5.- The “open” version of the curved panel, CRO. Dimensions are in meters. Panel thickness is 5 cm.

The response from (CRO) is identical to the response from (CR) for normal incidence/reflection. For configurations (ii) and (iii), CRO shows fluctuations on the order of 3 dB that are not present in the response from (CR). However, narrow band fluctuations of such small magnitude are considered negligible.

THIRD STUDY

A third study is conducted to investigate the influence of curvature radius on the frequency response. The radius of curvature is halved from 0.75 meters (CRO) to 0.375 meters (CROA) to 0.1875 meters (CROB). Results for reflectors with various curvature radii are shown in Figure 6.

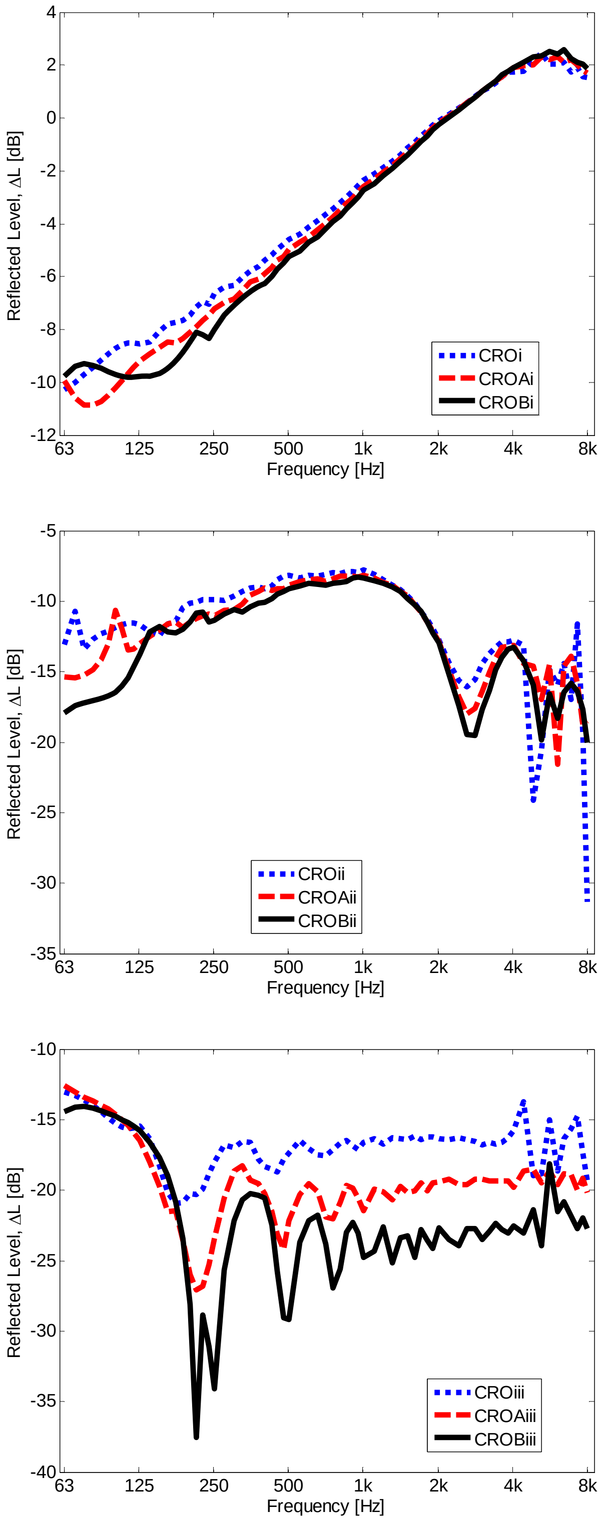

Figure 6.- Responses for panels of various curvature.

For the normal incidence/reflection configuration (i), the responses for each panel are nearly identical. For 45-degree incidence/reflection, configuration (ii), the responses are also nearly identical between the frequencies of 125 Hz and 4 kHz. Below 125 Hz the panels with the greater radius reflect more energy, and above 4 kHz there are differences in the fine structure of up to 10 dB. For configuration (iii), the receiver outside of the specular zone, the response level is approximately the same for all panels below 125 Hz. Above 125 Hz, a larger radius leads to a higher reflected SPL. The increase in scattered SPL with doubling of radius is 3 dB.

CONCLUSIONS

It has been shown using 2D BEM that reflector panels with convex edges have clear advantages over common flat reflector panels as well as purely round reflector panels. Reflector panels with convex edges (CRO) perform better than completely round reflector panels (S) in the specular reflection zone because they reflect much more energy in the geometrical acoustical range. For the typical dimensions considered here (a 1.5 meter reflector panel placed 15 meters above the source and receiver plane) the increase in level from a purely round reflector is approximately 13 dB for normal incidence and approximately 10 dB at mid frequencies for 45° incidence. Furthermore, the reflector panel with convex edges performs better than the flat reflector outside of the geometrical reflection zone by approximately 6 dB per octave increase.

References: [1] L.L. Beranek: Acoustic Measurements. New York: John Wiley and Sons, 1949. Page 109.

[2] H. F. Olson: Direct Radiator Loudspeaker Enclosures. J. Aud. Eng. Soc. **17, No. 1**(1969) 22-29.

[3] J.H. Rindel: Attenuation of Sound Reflections from Curved Surfaces. 24th Conf. on Acoust.: Strbske Pleso (1985).

[4] L.L. Beranek: (1992). "Concert Hall Acoustics—1992," J. Acoust. Soc. Am. **92 No.1**(1992) 1-24.