Open Noise-Barriers – investigations on scaled models

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Introduction

Noise barriers are indispensable as means of noise abatement. To meet the legal limits, very high noise barriers or other efficient buildings e.g. laterally open overhead noise barriers like galleries, or covered troughs are needed. Not only because of their higher hights they need a bigger foundation, but also because of their wind load.

The open noise barriers in this paper are acoustic lenses. They show an analog behaviour for sound waves like optic lenses for light. It's possible to focus or direct waves with them. With a adequate arrangement of such a lens-construction it should be possible to get a local noise reduction despite of its open construction. And this with the advantage of a partly transparent and light body.

Analogy: Optical - Acoustical Lenses

Everybody who wears glasses thinks of glass or plastic lenses when he hears the word lens. With those lenses it is possible to focus light. A light ray will be refracted when it passes from one medium to another, if the two media have different speed of propagation. The focal length is a function of the radius of the lens. Parallel light rays can be focused in one point. Or from the other side, with a lens one can produce parallel light rays if there is a point source in the focus. The paths through the lens have different lengths, but they are in phase behind the lens. In acoustics there is the effect of refraction if a sound ray enters from one medium to another with a different sound speed as well.

One can hear this during different weather conditions in a few hundred meters distance from a highly frequented road. In normal weather conditions the noise of the road is not very present. But if the weather conditions are inverted, which means that there is warmer air in high layers, you can hear the road very clearly. Because here we have the situation that sound will be refracted down to the surface again. This is because of the fact, that cold air has a higher density than warm air. So we have different sound speeds.

If you would like to build a homogeneous acoustic lens in analogy to optics, you need a bubble of a gas (which has a different sound speed than the air) in the air with a acoustical ineffective shell. And that is not practicable. But there are possibilities to construct lenses for acoustic applications. These lenses change the sound path, and from outside it looks, as there would be an other sound speed inside the lens. These lenses can be built to focus sound in one point. There are two ways of construction:

The redirective lens

The redirective lens consists of twisted lamellae with constant spacing in between. The width of the lamellae decreases from the centre of the lens to the rim, the envelope building the shape of a lens (figure 1). The sound waves are forced to take a longer path through these channels of the lens. The length of the lamella and therefore the channel length are calculated in a way that all sound waves have the same travelling length after leaving the lens. That means, they are in phase now. A so constructed lens transforms the radial waves into plane waves, if the point source is in the focal point of the lens (figure 2, left). By increasing the distance between source and lens, the waves are no longer in phase. In this case we have an image of the point source (figure 2, right).

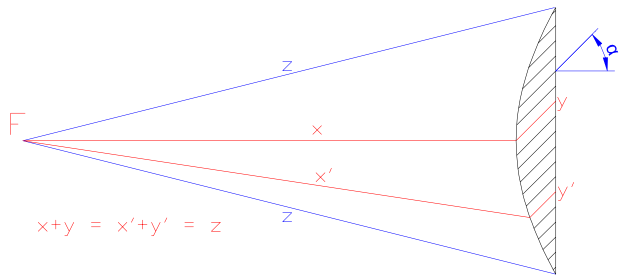

Figure 1: Geometry of the acoustic redirective lens

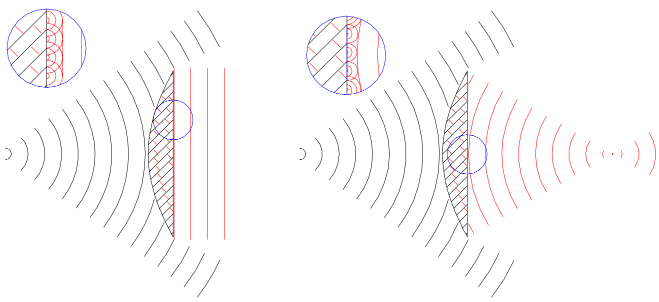

Figure 2: The effect of the redirective lens is given by the length and the angle of the channels

The refractive index of the redirective lens is equal to the reciprocal cosine of the lamellae-angle.

$$n = \frac{1}{\cos(\alpha)} \qquad \alpha\text{: } \textit{angle of lamellae } [°]$$

The stripe lens

A stripe lens is built with regularly spaced scattering pieces which form a lens (see figure 3). The sound waves entering the lens and the scattered sound waves superimpose in a way, that the effective speed of propagation inside the lens is decreased. Therefore it is necessary that the size of the scatters and their spacing is less than the wavelength.

Due to the scattering pieces the molecules of the air can not oscillate as freely as without them. From the outside it seems as if the interior air had a higher density than the surrounding air. Therefore a refraction of the sound waves at the rim of the lens take place. To illustrate this phenomenon, one can imagine this: The lens is placed in a sound field. The scattering pieces represent obstacles. They hinder the propagation of the air-pressure oscillations. The more obstacles there are, the more inhibited the propagation is. Thus the speed of the sound waves is reduced less at the rim of the lens than in the middle, where more scattering pieces are situated.

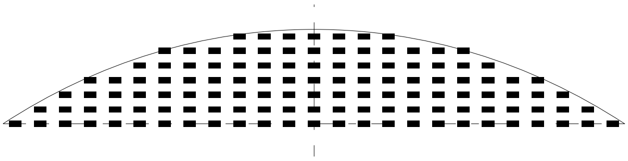

Figure 3: Build up of an stripe lens

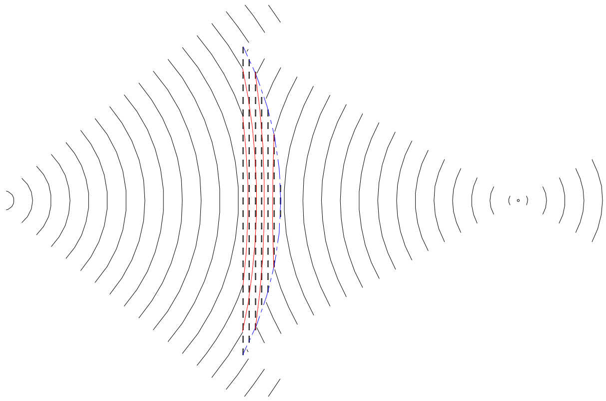

Figure 4: Because of the scattering pieces the speed of propagation for sound waves in the lens is reduced

Due to the scattering pieces the effective density of the air (ρ_0) inside the lens is increased:

$$\rho = \rho_0 + \frac{1}{2} \cdot \rho_0 \cdot N \cdot V_{Sk}$$

ρ_0: resting air
ρ: effective density of the air in the sound-field
N: number of scattering pieces per volume
V_{Sk}: volume of one scattering piece

The refractive index of a stripe lens equals the ratio of the speeds of propagation and is conversely proportional to the square root of the ratio of the densities:

$$n = \frac{c_0}{c} = \sqrt{\frac{\rho}{\rho_0}}$$

Results

The following diagrams show the results of the first measurements with redirective lenses.

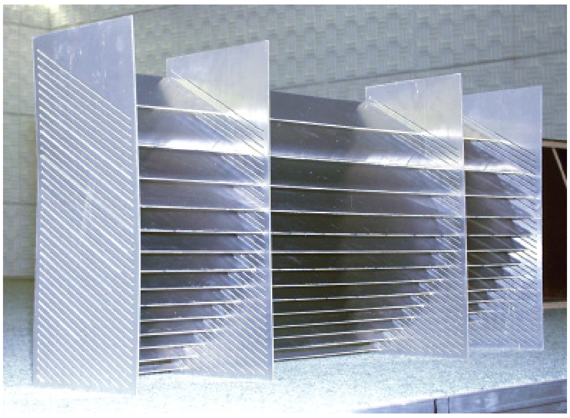

Figure 5: redirective lens 30°, 30mm distance between Lamellae

The one dimensional directivity diagram shows the difference between the measurement of the lens to free field conditions for 15 third octave bands and their cumulated level. It was taken in the distance of the image point. Clearly visible is the amplification of about 6 dB in the cumulated level and the adjacent minima.

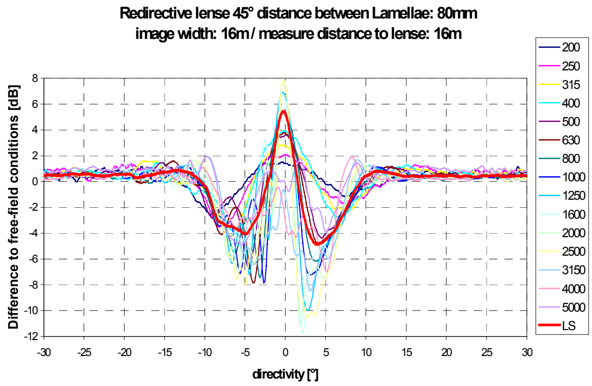

Figure 6: 1D-directivity through the focus

In the 2 dimensional scan one can clearly see the maximum (in dark green). Next to it, the strong decrease of the level is visible.

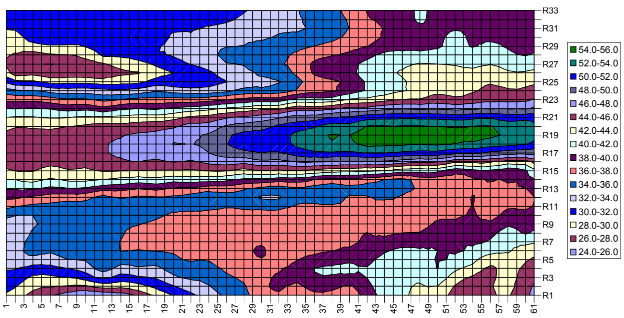

Figure 7: 2D Scan 6,3 kHz-1/3-octave

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