London South Bank University

ROYAL OPERA HOUSE

Acoustic Conditions in Orchestra Pits:

Are Metadiffusers a Potential Solution?

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Introduction

Directives on noise control are of major concern as opera performances tend to generate very high sound levels, especially in the area of the orchestra pit – the sunken cavity between the stage and audience. In such context, management faces a difficult task conforming to noise regulations as they must balance the sometimes competing demands to (i) dutifully protect their employees – musicians and others – from any harmful 'sounds' or 'noise' that might be generated, and (ii) deliver world-class operatic art for the public, where noise regulations might compromise the culture of the art form.

Question

Is it **possible** to create acoustically **diffusive** and/or **absorptive** surfaces that could **fit within the tight space** available in orchestra pits ($\approx$ **10 cm** limit) and thus help **enhance** the difficult **acoustic conditions** in orchestra pits?

Metamaterials & Metadiffusers

Materials achieving subwavelength performance, affecting longer wavelengths than what the material would genuinely allow, fall under the vast category of metamaterials, i.e. materials that obtain their extraordinary physical properties from their structures rather from their chemical composition. A proper definition of metamaterials could be termed as a'class of structured composites whose wave functionalities arise as the collective manifestations of its locally resonant constituent units [2]'. A basic example of an acoustic metamaterial could simply consist of an array of Helmholtz resonators (HRs), achieving subwavelength features due to their quarter-wavelength resonance.

The concept of metadiffusers (see Figure 1) was recently presented by Jimenez et al. in July 2017 [1], who developed a metamaterial-inspired sound diffuser working on a deep-subwavelength regime. The aim of such metasurfaces is to modify the dispersion relations inside each slit by loading one of their boundaries with a set of HRs. The sound propagation becoming strongly dispersive due to viscous losses, the speed of sound, c_p, is drastically reduced. As each slit behaves as a deep-subwavelength resonator, the effective depth of the slit can be substantially decreased according to $L = c_p/4f$.

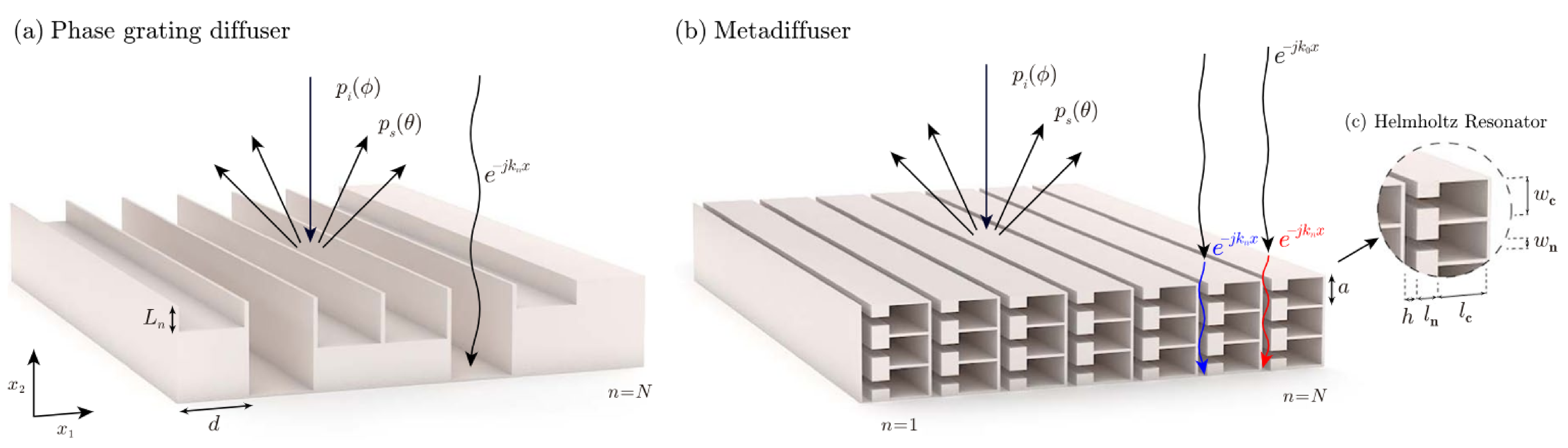

Figure 1: (a) Scheme of a QRD Schroeder diffuser composed by N = 7 wells or quarter-wavelength resonators. (b) Metadiffuser composed of N=7 subwavelength slits, each loaded with M = 3 HRs. (After Jimenez et al. [1])

Broadband Optimal Metadiffuser

Jimenez et al. proposed a broadband metadiffuser with a maximum normalized diffusion coefficient in the optimal frequency range of f_{low} = 250 Hz to f_{high} = 2 kHz, with variable resonator dimensions and limited to 3 cm thickness, as shown in Figure 2.

It can be seen that the prospective maximum normalized diffusion coefficient of the broadband metadiffuser stands out when compared to both a 3 cm and 56 cm thick QRD, with values between 0.4 and 0.7 in the frequency range of 300 Hz to 2000 Hz. This shows the great potential of metadiffusers, as the geometry required to disperse sound in a broad frequency range has been reduced by a factor of almost 1/20th of the conventional designs, affecting even lower frequencies.

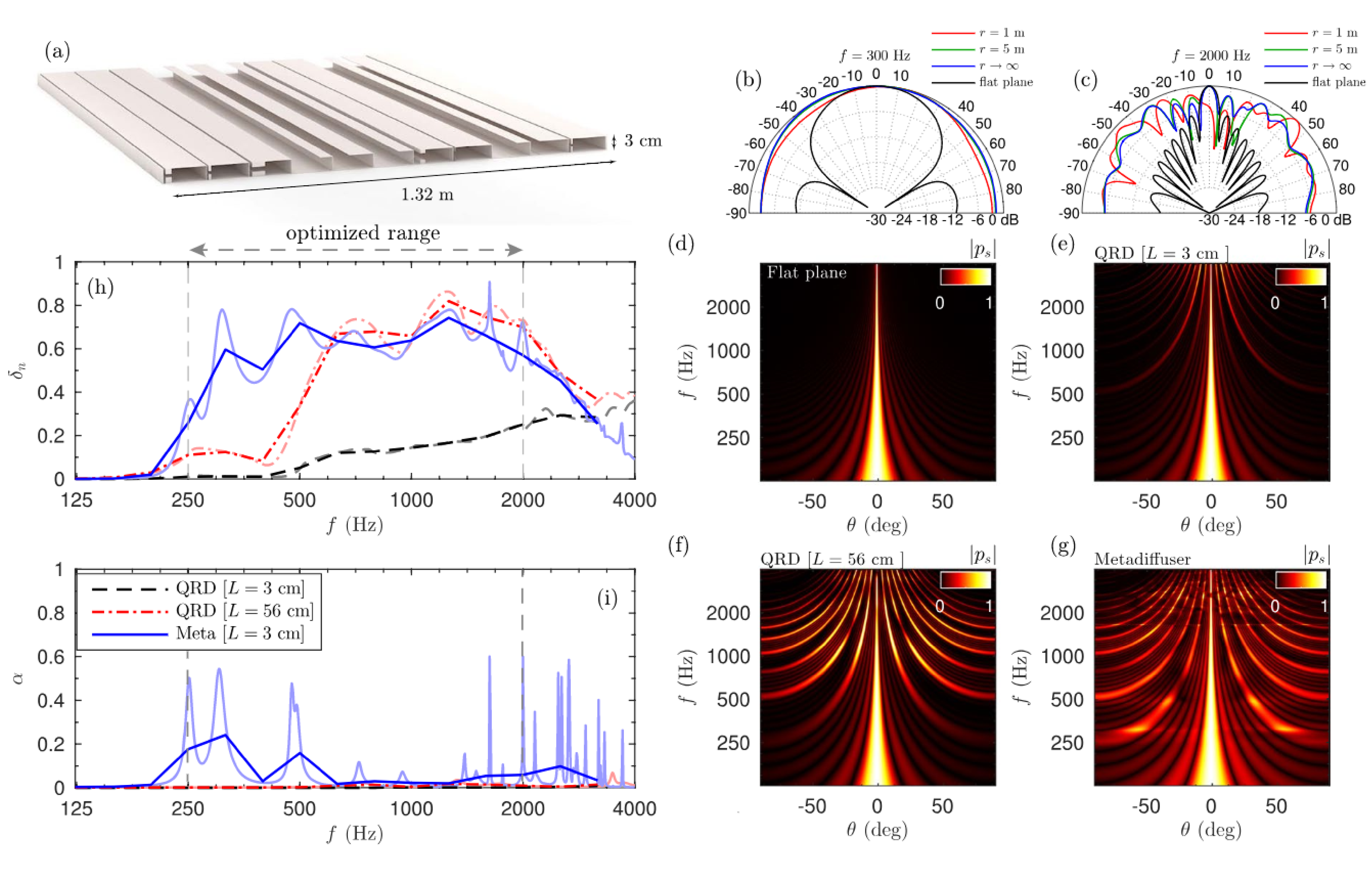

Figure 2: Visualization of the broadband metadiffuser design with near and far field polar responses for different surfaces along with their diffusion and absorption coefficients (After Jimenez et al. [1])

Prototyping and Scattering of a Broadband Metadiffuser

A 1:1 prototype of the broadband metadiffuser was built using 3 mm thick acrylic sheets that were laser-cut and welded together over an MDF board covered by a PVC sheet using a plastic solvent. The necks of the different HRs were built using balsa wood sticks in order to minimize the weight being applied to the endpoint of each subwavelength slit. Scattering measurements of the prototype were conducted following AES-4id-2001 with results plotted in Figure 3. The latter can be quite variant due to measurement uncertainty and prototyping errors. Discussions with N. Jimenez and V. Romero-Garcia helped enlighten such problems.

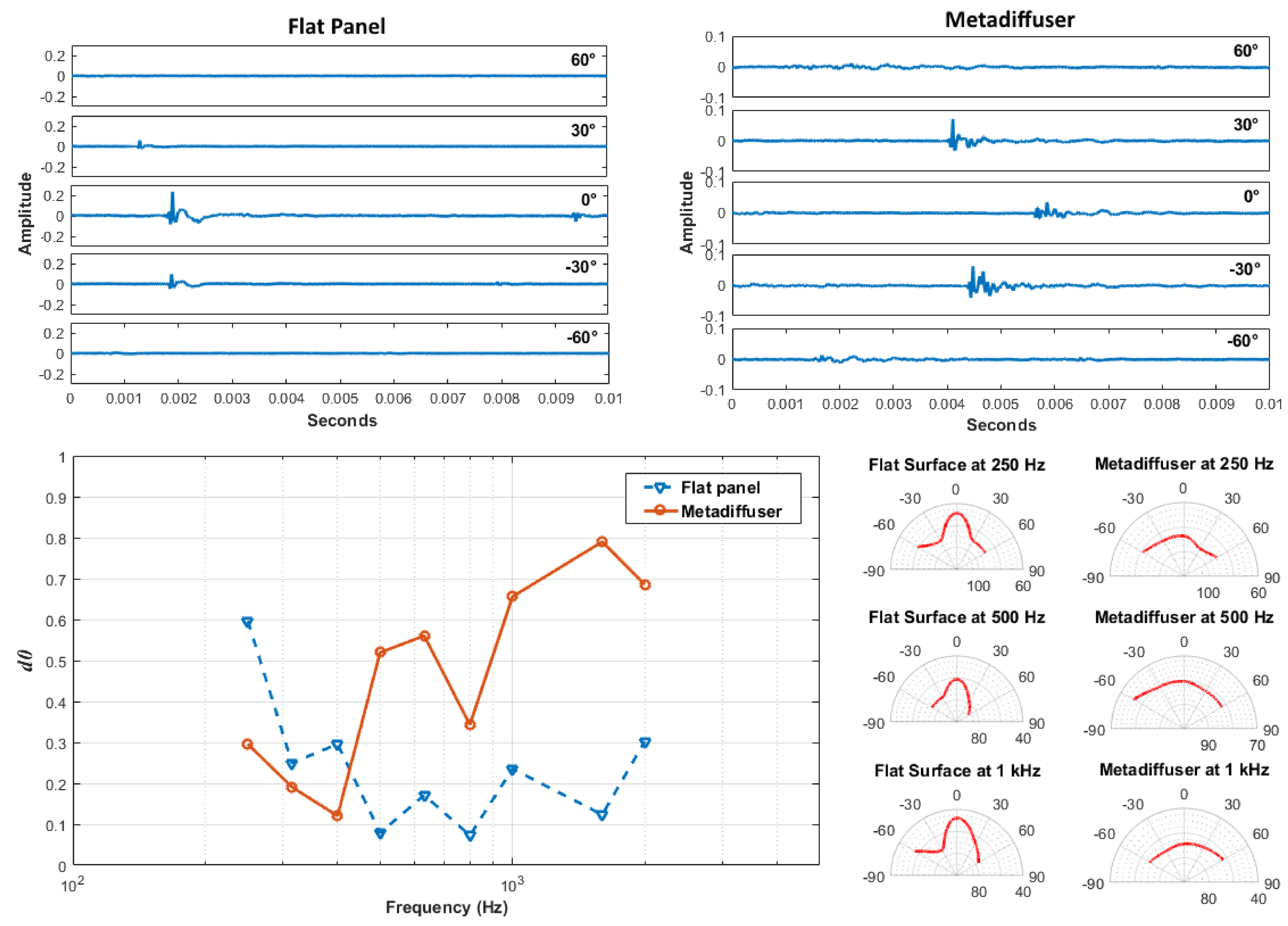

Figure 3: Reflected impulse responses at normal incidence over a flat surface and the broadband metadiffuser prototype along with their autocorrelated diffusion coefficients and scattering plots

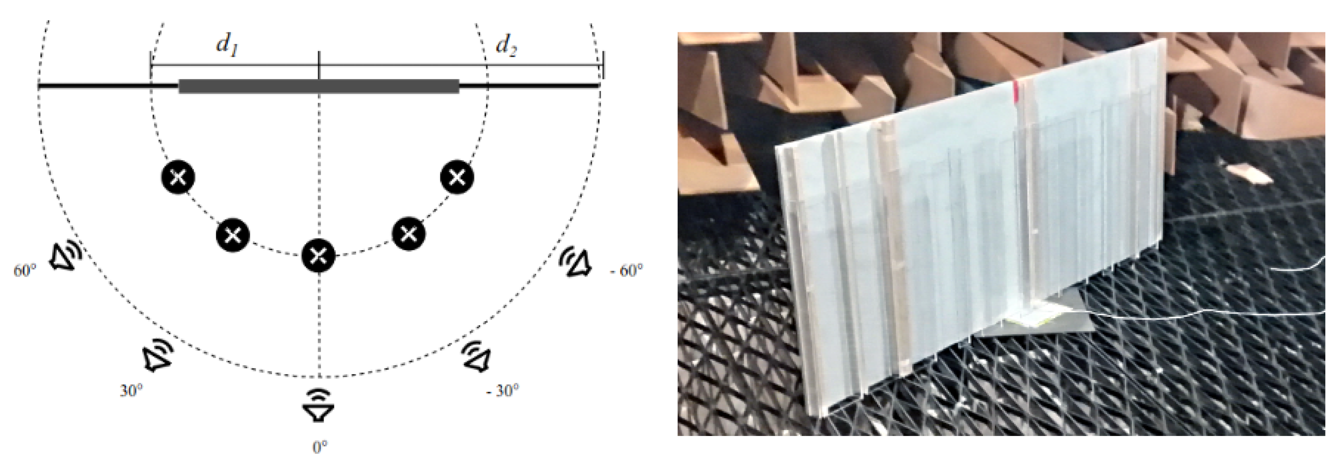

Figure 4: Scattering measurement of the broadband metadiffuser prototype

Prototyping Errors & Design Considerations

1. Closed panel terminations and total length were not featured in the tests but are required so that slits can affect low frequencies more effectively.
2. Apparent worse acoustical diffusion in low frequencies (f < 400 Hz) and slightly high diffusion values ($f \sim$ 1.6 kHz) may be due to measurement uncertainty (poor spatial sampling around the test surface with $\Delta_{AngleSampling}$ = 30°)
3. Dip in d_0 in Figure 3 around f = 800 Hz could be explained by the diffraction of sound around the panel due to its reduced length (0.55 m instead of 1.3 m), as $\lambda_{800Hz} \approx$ 0.5 m.

Conclusions

- Even if some mistakes were made for the prototyping of the broadband metadiffuser, scattering measurements still demonstrate an **important acoustical difference** between a **flat surface** and the **broadband metadiffuser**, with an average difference of **0.3** to **0.4** in diffusion coefficients for a **thickness** increase of just **3 cm**.
- This significant change in dimension for diffusing surfaces holds a **great potential** of applications for **spaces with limited geometry**, such as orchestra pits.
- This is an **early proof of concept** that metadiffusers are likely to behave as predicted.

References

[1] N. Jimenez, T.J. Cox., V. Romero-Garcia, and J.-P. Groby. Metadiffusers: Deep-subwavelength sound diffusers. *Scientific Reports*, 7(5389), 2017.

[2] G. Ma and P. Sheng. Acoustic metamaterials: From local resonances to broad horizons. *Science Advances*, 2(2), 2016.

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