Vibro-acoustic modeling, analysis and optimization using COMSOL Multiphysics

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Acknowledgement
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HDB

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Contents

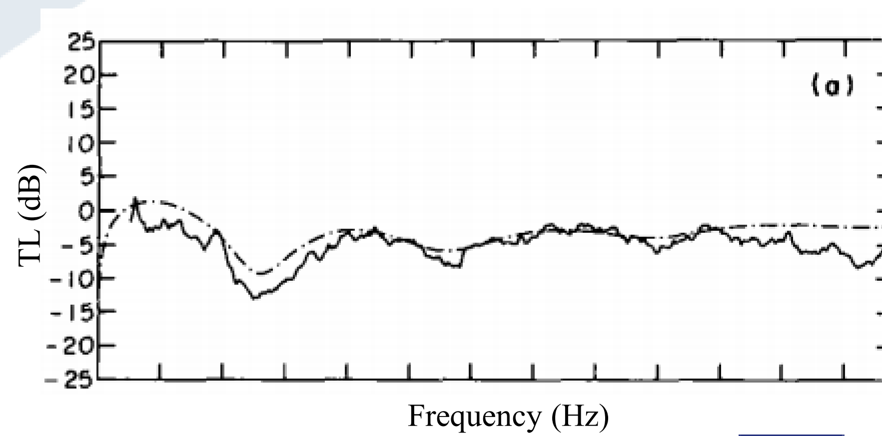
- Building-Development of noise mitigation window
- Research-Acoustic metamaterial
- Material-Porous absorbing material

Interests & capabilities

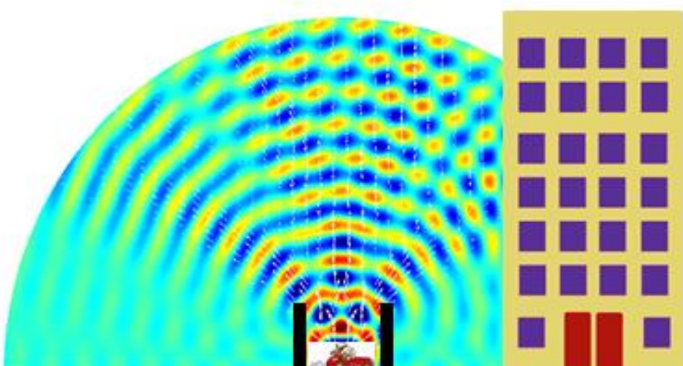
Vibro-acoustic modeling; Noise and vibration control; Architectural acoustics; Aerospace and automotive engineering; Active noise control; Acoustic metamaterial

Ventilation window

HDB window

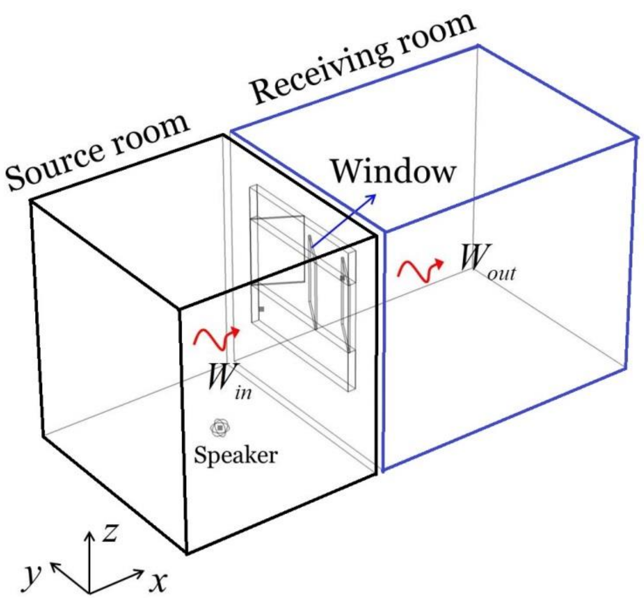


Sound transmission loss of small aperture
Oldham, JSV, 1993



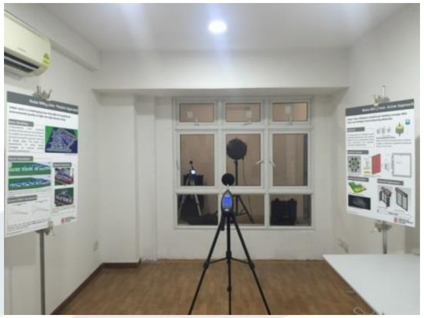
Sound barrier simulation

Sound Reduction Index



Measuring window sound insulation
ISO-10140

Source room

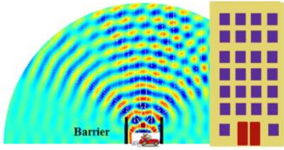


Receiving room

Testing facility at HDB

Sound reduction index (SRI)

$$R = 10 \times log_{10}(W_{\text{in}}/W_{out})$$



Outdoor noise level

+

Window SRI

+

Room correction

Indoor noise level

$$L_{in} = L_{out} - SRI + Cr$$

Why SRI is important?

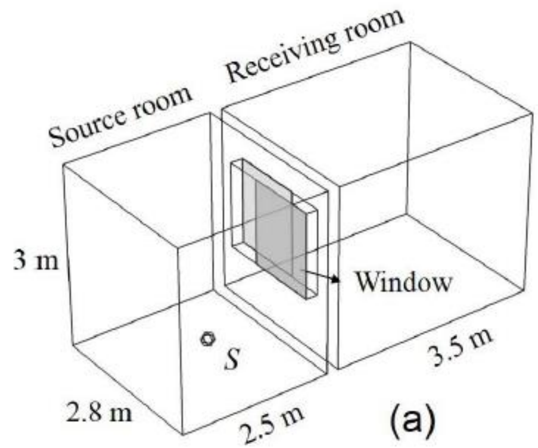
Sound Reduction Index

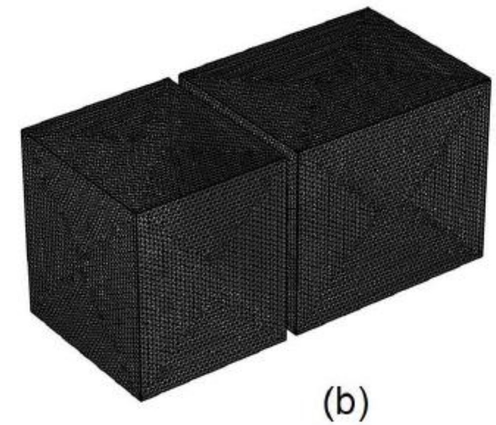
Predicting SRI using FEM:

$$\mathrm{SRI} = 10\log_{10}(W_S / W_R) = L_S^W - L_R^W$$

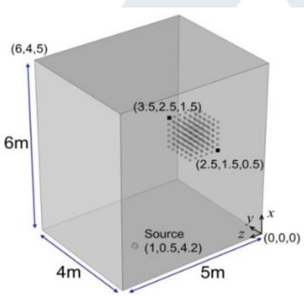
Sound power of a diffuse room:

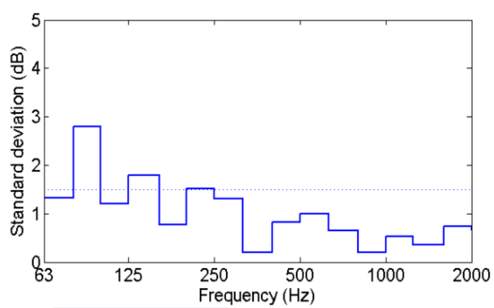
$$L_S^W(f_c) = 10\log\left[\frac{A}{2\rho_0 c_0}\left(\frac{\sum 10^{L_S/10}}{N_S}\right)\right]$$

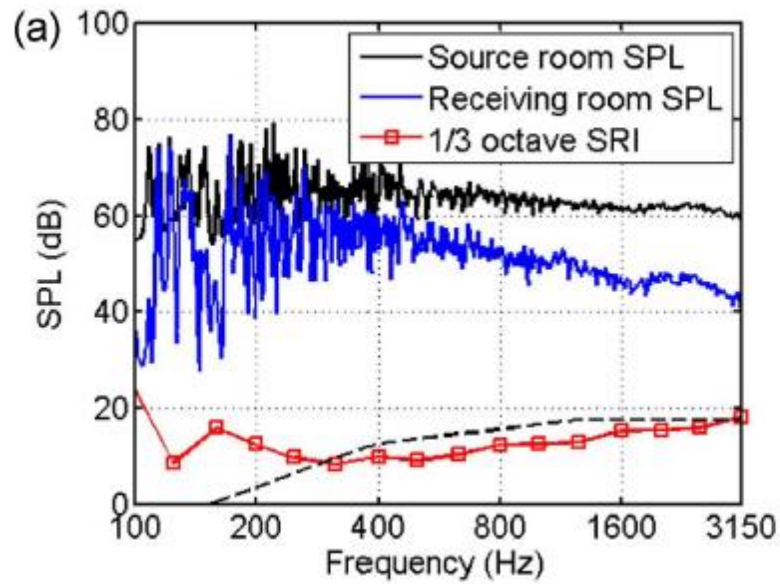




Reverberation in source room

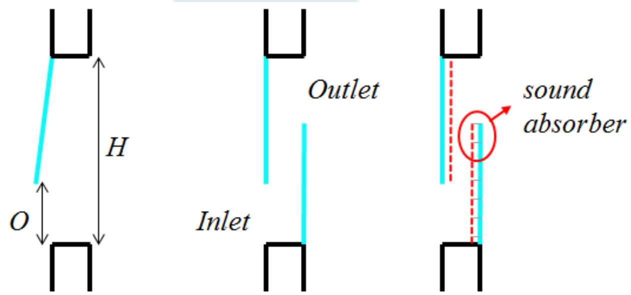




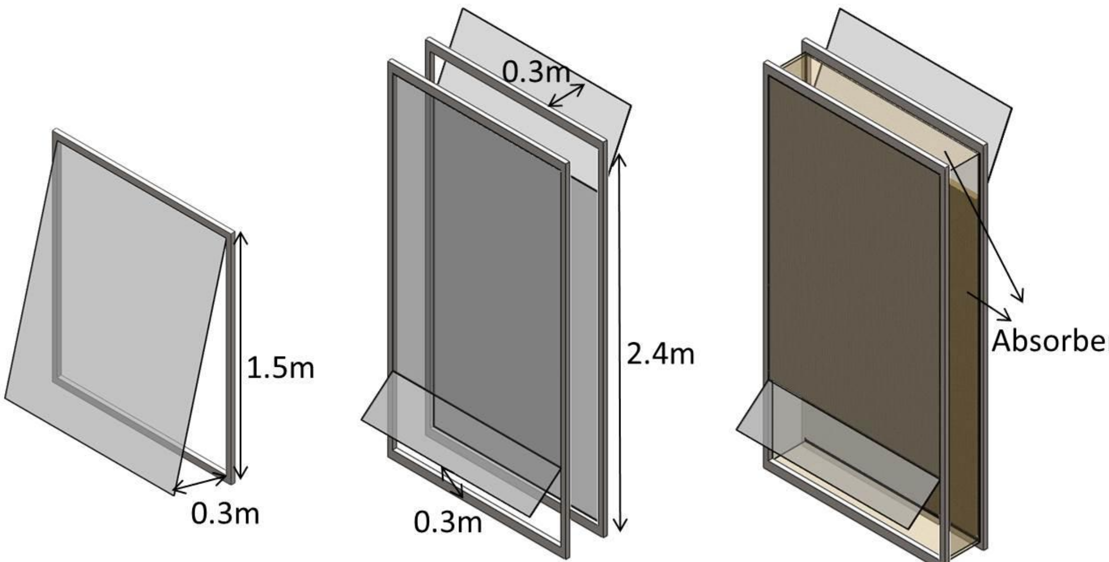


Prediction vs. Experiment

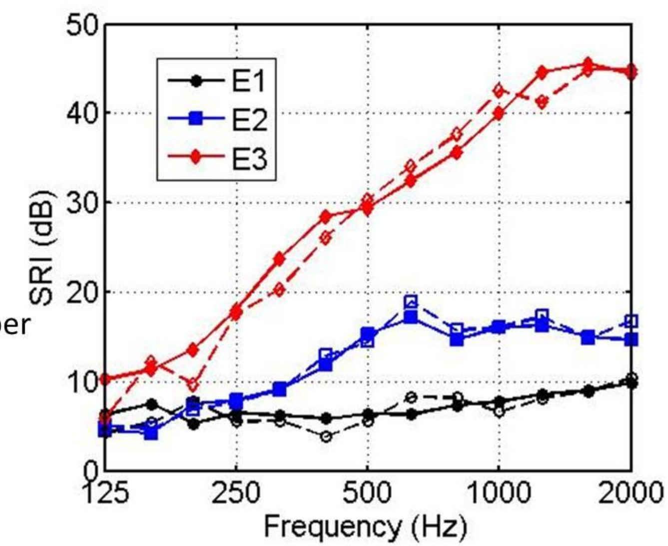
Typical window configurations



Experimental data from Delta acoustics, Denmark



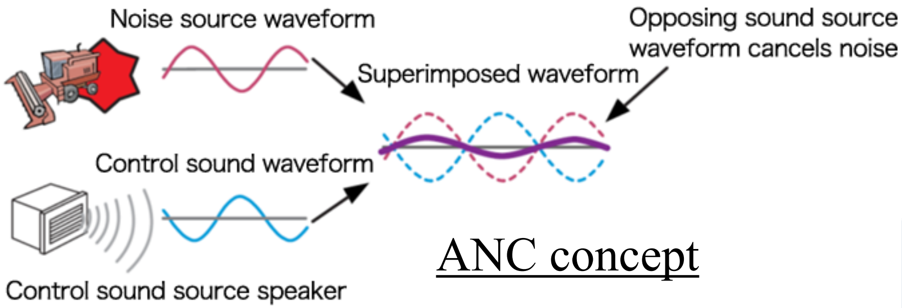
E1: Standard top-hung   E2: Open double glazing   E3: window with absorber



Solid: experiment   dashed: prediction

Predicted SRI shows good agreement with full-scale experimental results

Active Noise Cancellation



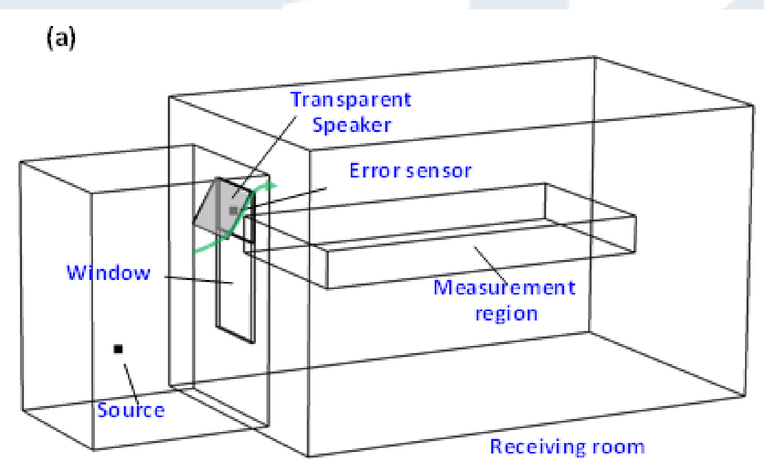
ANC concept

Vs.

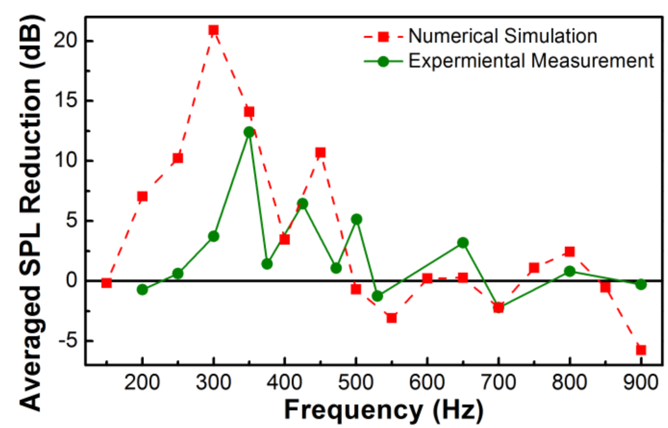
Traditional loudspeaker

Transparent speaker

ANC configuration



Simulation and experiment results



P1: Primary; P2: Secondary

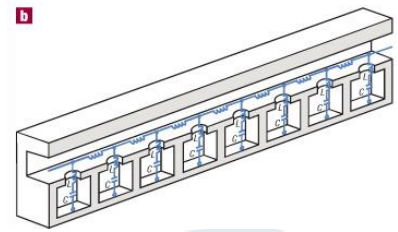
ANC Target: P2 cancels P1

$$q' = -q(P_1 / P_2)$$

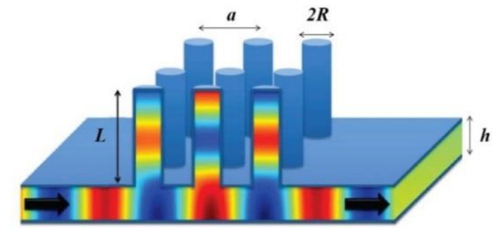
IHPC A*STAR

Acoustic metamaterial

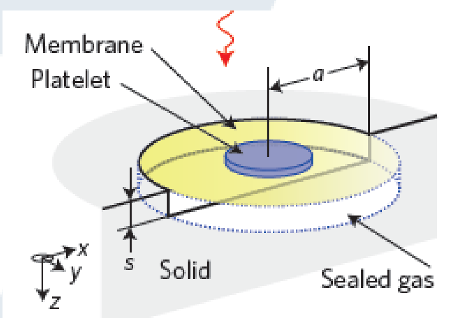
- Artificial structure
- Acoustic stop-band
- Negative effective parameters
- Sub-wavelength property
- Tunable performance…



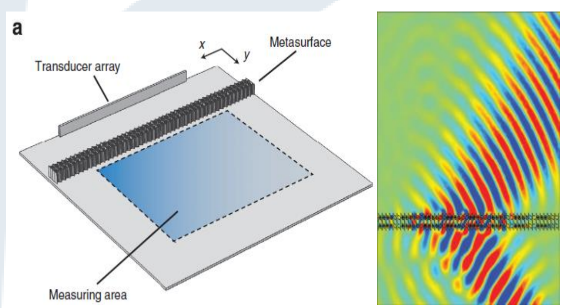
Fang, Nature materials **5**, 2006
Periodic Helmholtz resonators



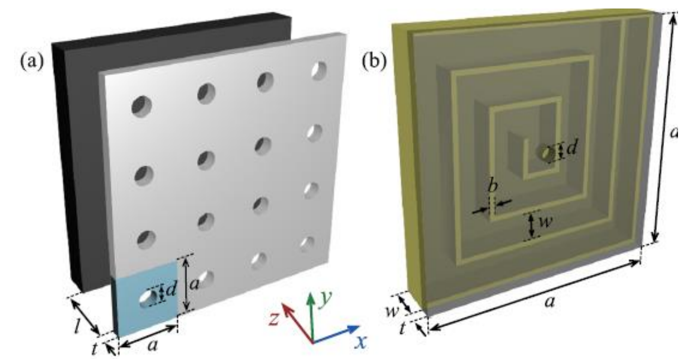
Physical Review B **85**, 2012
3D periodic resonators



Sheng et al.
Decorated membrane resonator
Both reflection & absorption



Nature communications, 2014
Wave modulation



Li and Assouar, APL 2016
Low-frequency absorption

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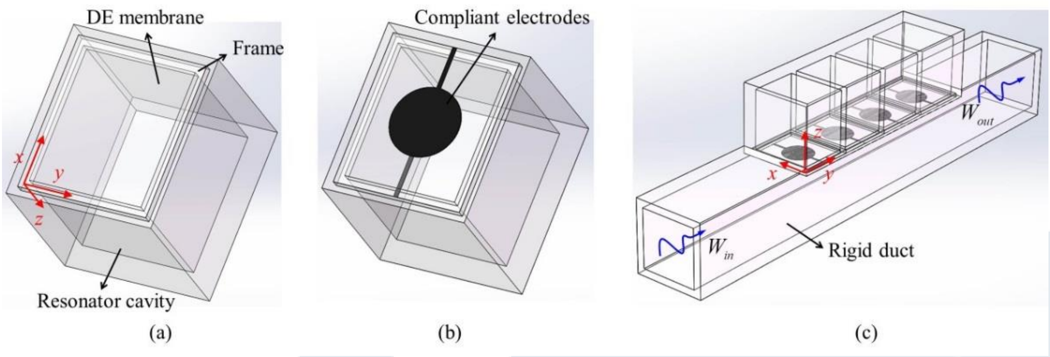
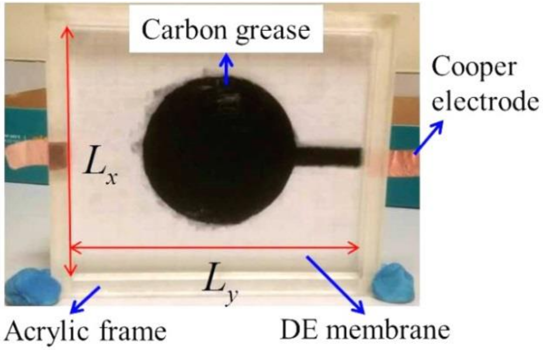
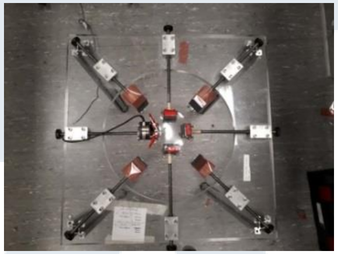
Membrane-type acoustic metamaterial

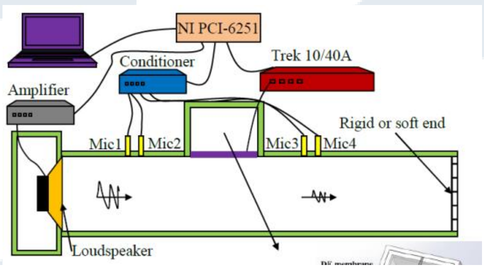


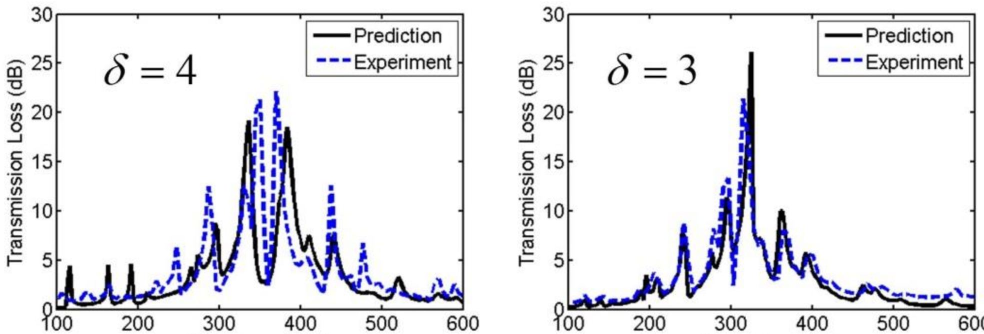
Tunable resonator with dielectric elastomer

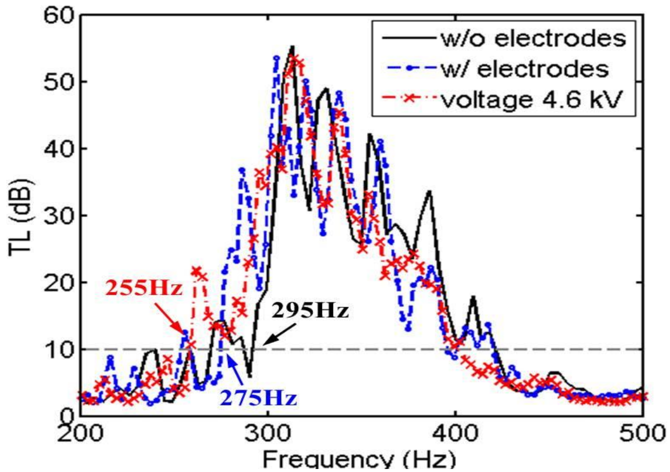


prototype









Frequency shift with voltage

Validation with different membrane pre-stretch ratio

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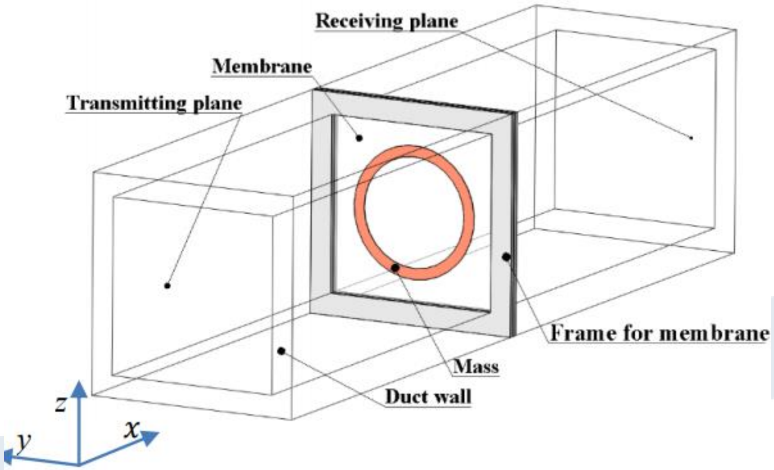
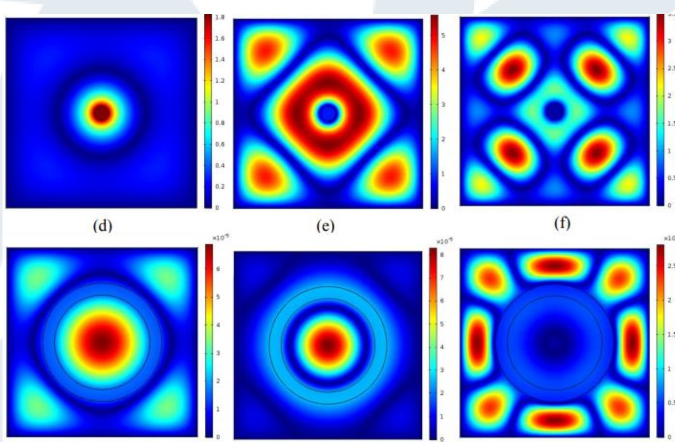
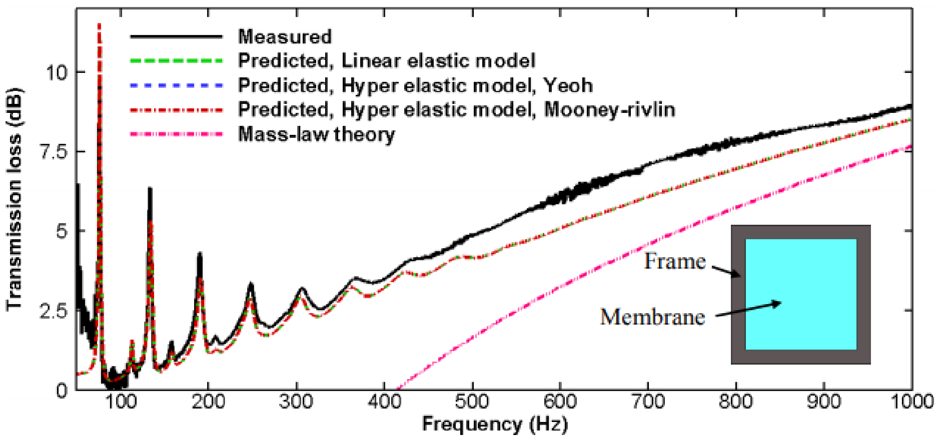
Membrane-type acoustic metamaterial

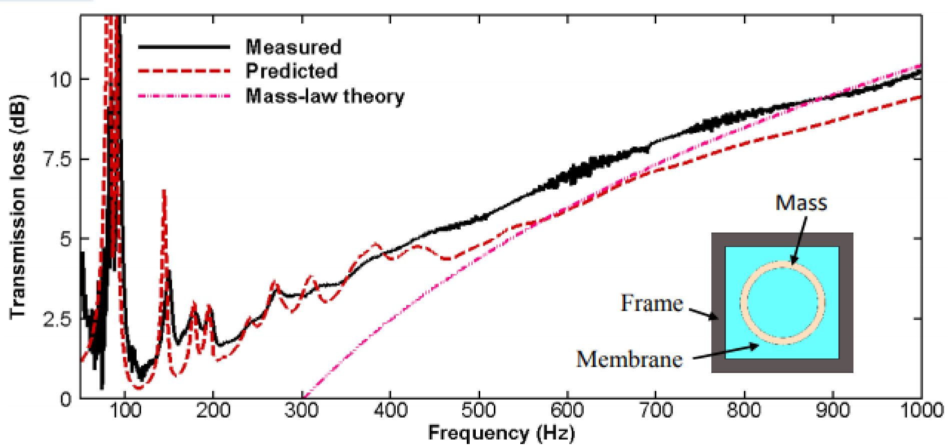


Membrane with distributed mass



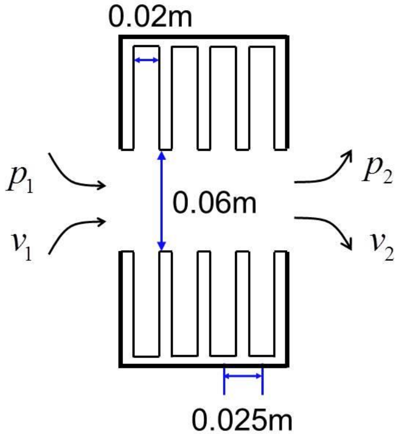
Mechanism study-vibration mode



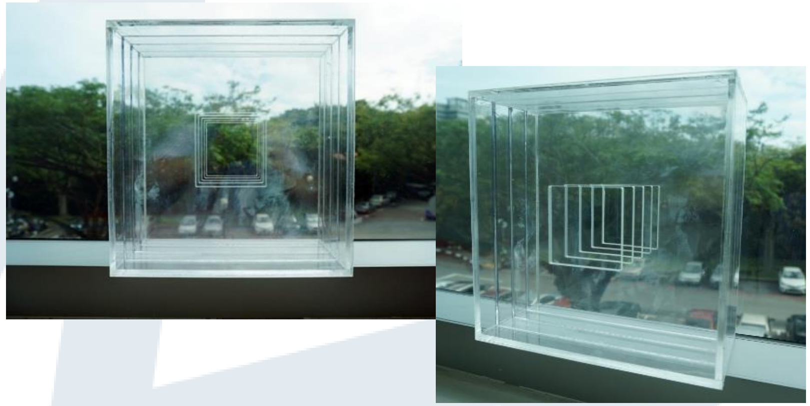


Comsol simulation vs. experiment

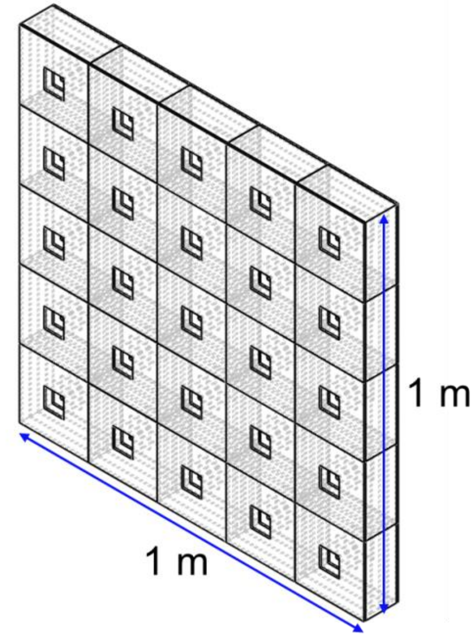
Acoustic metasurface



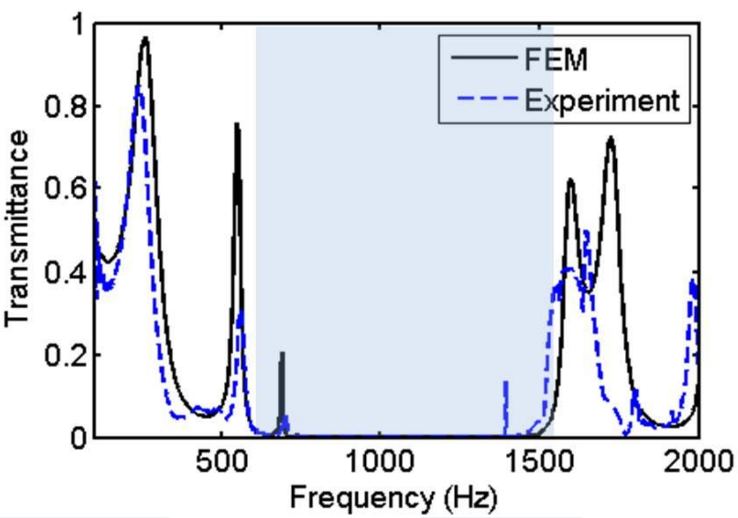
Periodic waveguide



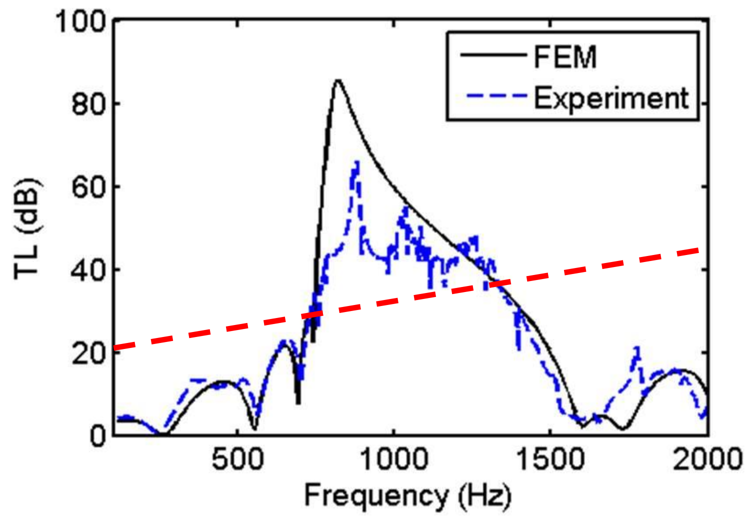
Fabricated sample



Metasurface for sound insulation



Transmittance



Transmission Loss (dB)

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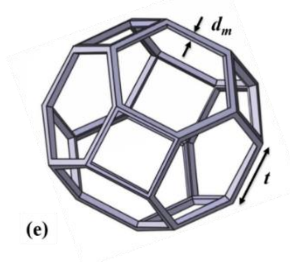
Metallic foam

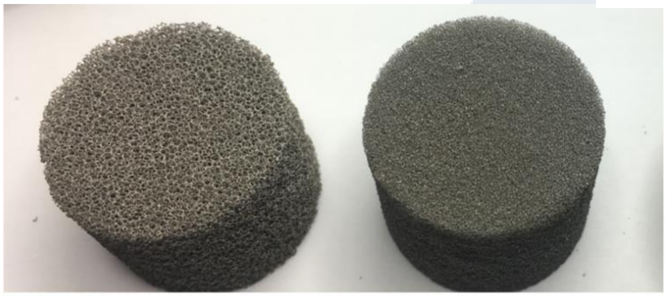
tetrakaidecahedron pore



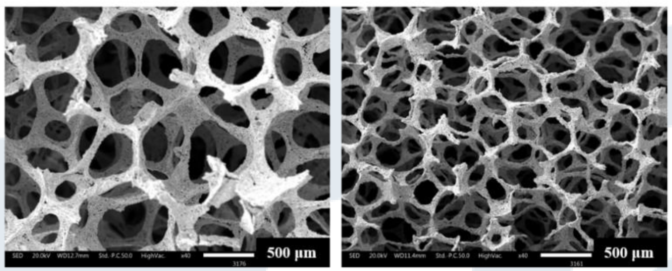
Impedance calculation

$$\tilde{\rho}(f) = \rho_0[1 + 0.0571(\frac{\rho_0 f}{\sigma})^{-0.754} - j0.087(\frac{\rho_0 f}{\sigma})^{-0.732}]$$

$$\tilde{c}(f) = c_0[1 + 0.0978(\frac{\rho_0 f}{\sigma})^{-0.700} - j0.189(\frac{\rho_0 f}{\sigma})^{-0.595}]^{-1}$$

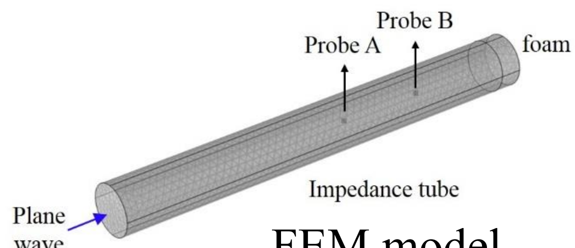


IN625 Foam A **IN625 Foam B**

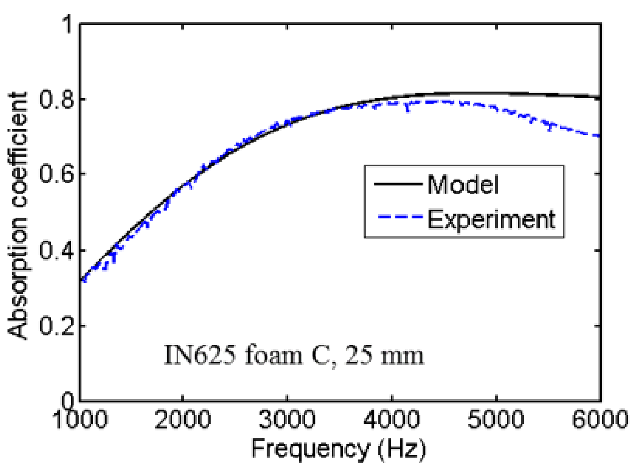


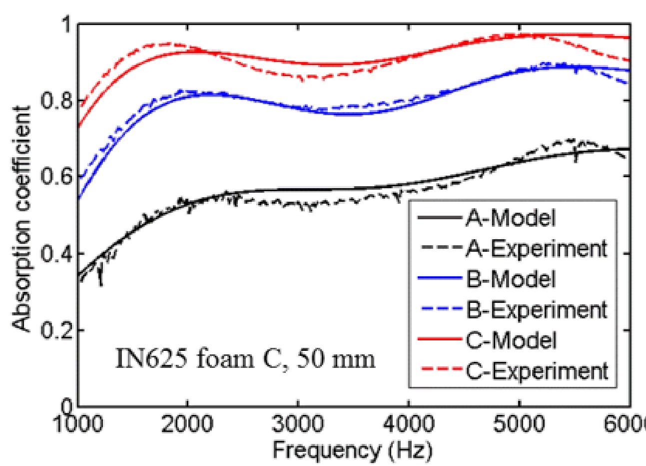
IN625 Open-cell foam

Impedance tube



FEM model





Conclusions

- Comsol Multiphysics is a useful FEM tool to conduct vibroacoustic research.
- Knowledge and experience is important to build correct models.
- The Optimization Module and Application Builder can be integrated to serve a wide range of industrial projects.

- Acknowledgment:
- Singapore Ministry of National Development and National Research Foundation under L2 NIC award No. L2NICCFP1-2013-9.
- Metal Foam Designs with Acoustic Damping Properties: Experimental and Simulation Studies, Inter-RI project with SIMTech

If you have questions & needs about noise and vibration control, acoustic product design, Please feel free to contact us:

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Thank you!