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An optimised sub-wavelength segmented membrane sound absorber

Andrew McKay
Ian Davis
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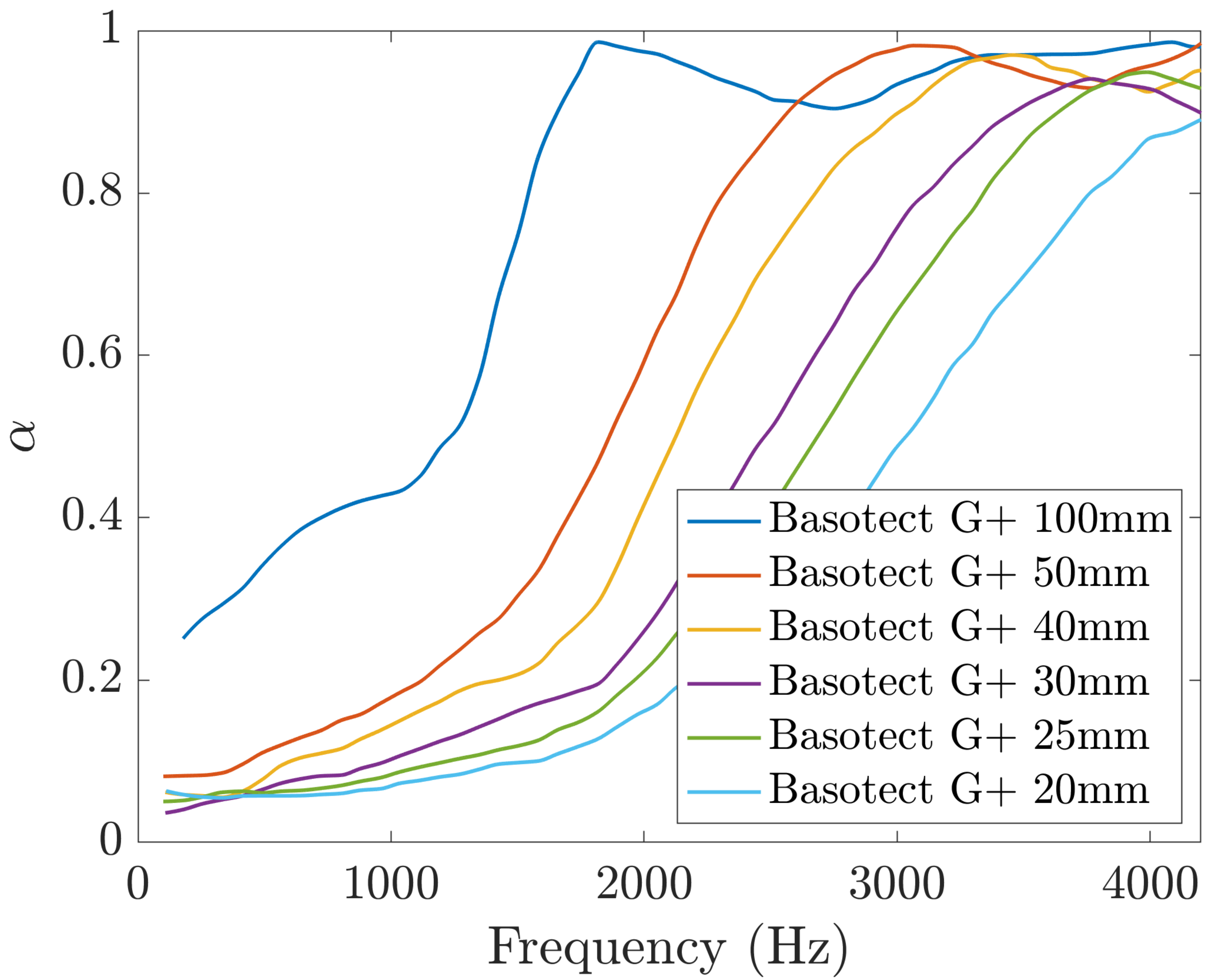
Existing absorbers

BASF Basotect G+

Melamine Foam

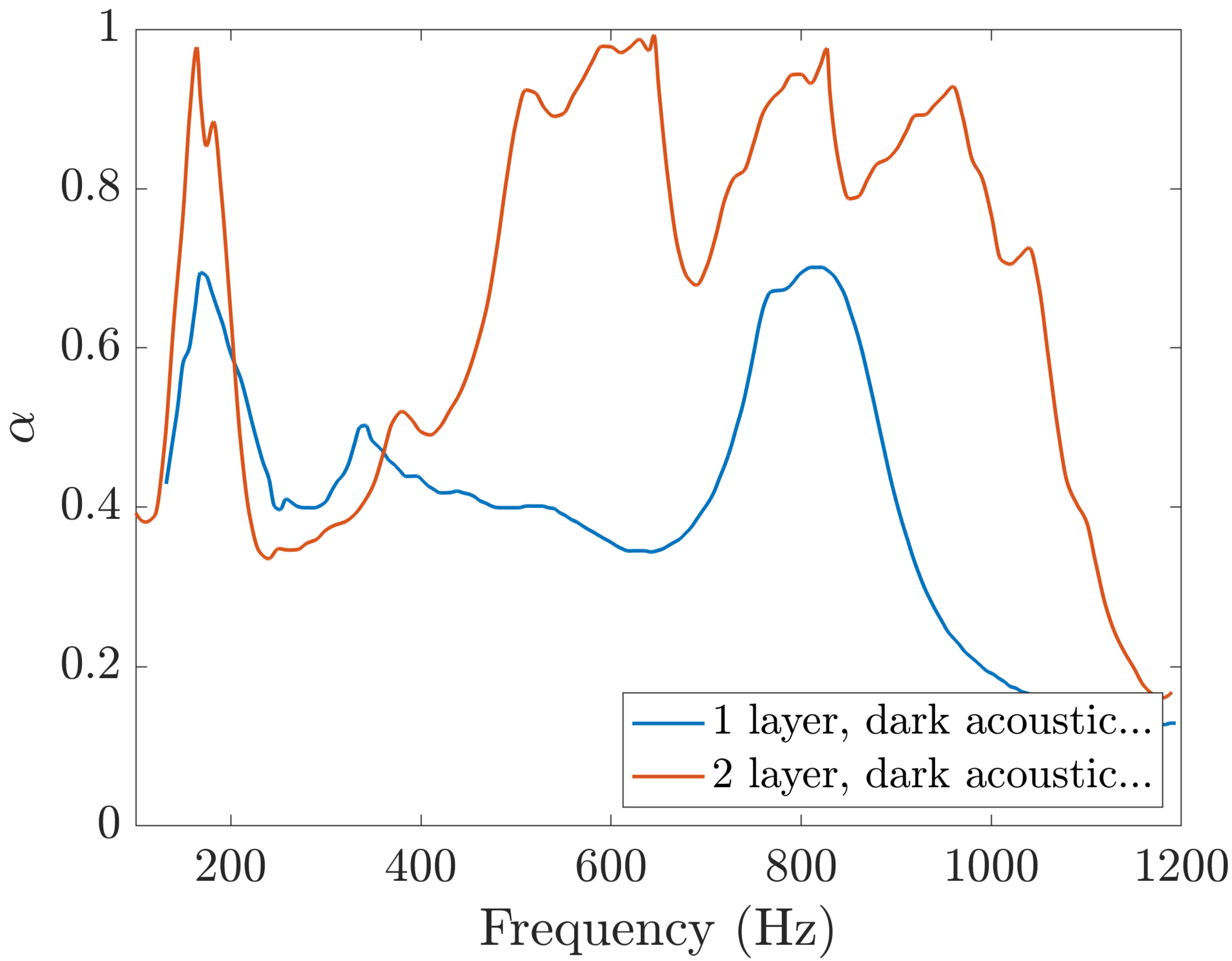
https://products.basf.com/en/Basotect.industry~plastics_rubber%7Cperformance_polymers.html



Existing absorbers

J. Mei, G. Ma, M. Yang, Z. Yang, W. Wen, P. Sheng, Dark acoustic meta-materials as super absorbers for low-frequency sound, Nature Communications 3 (2012) 756.

Decorated membrane



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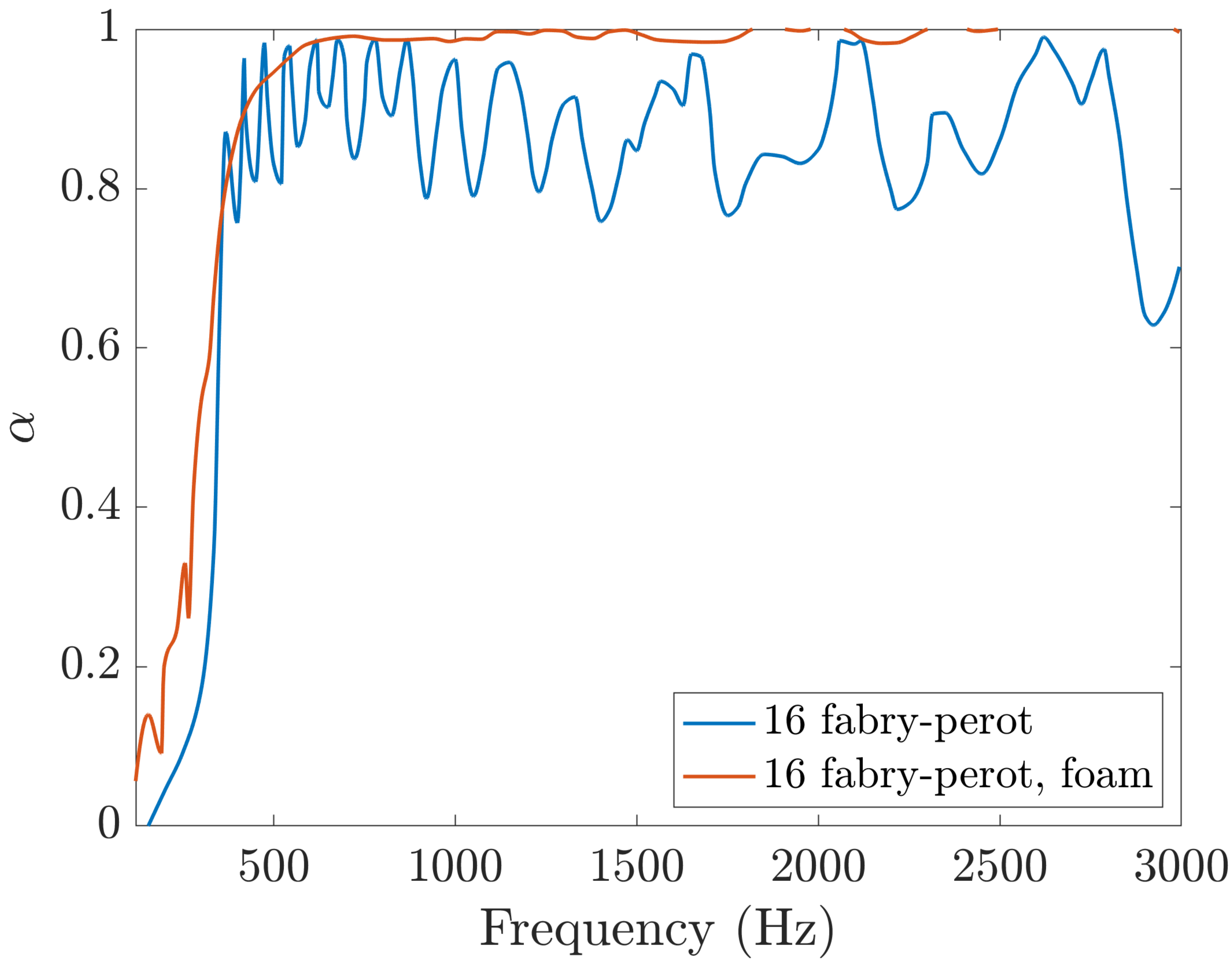
Existing absorbers

M. Yang, S. Chen, C. Fu, P. Sheng, Optimal sound-absorbing structures, Mater. Horiz. 4 (4) (2017) 673-680.

16 folded fabry-perot resonators



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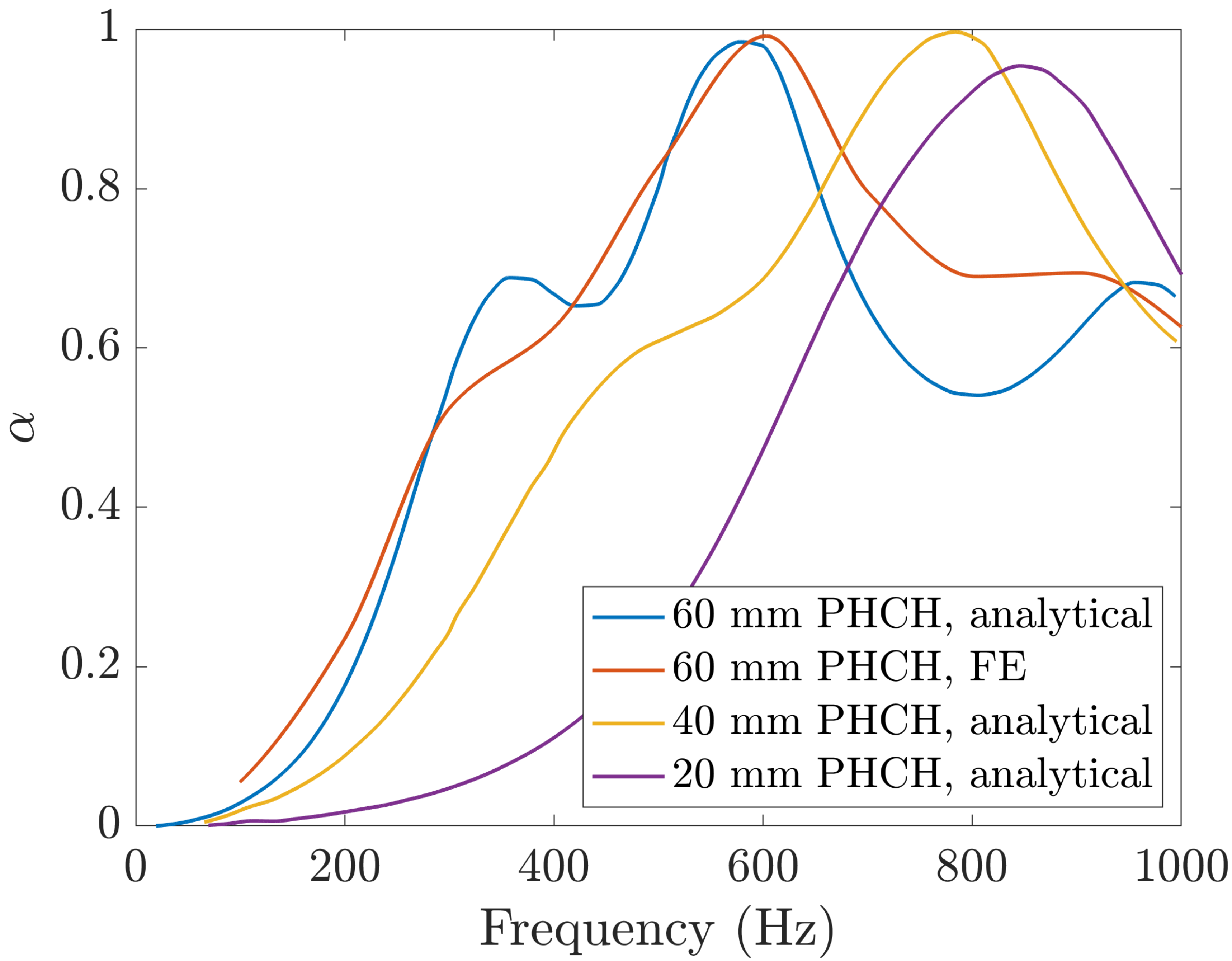
Existing absorbers

Y. Tang, S. Ren, H. Meng, F. Xin, L. Huang, T. Chen, C. Zhang, T. J. Lu, Hybrid acoustic metamaterial as super absorber for broadband low-frequency sound, Scientic Reports 7 (January) (2017) 1-11.

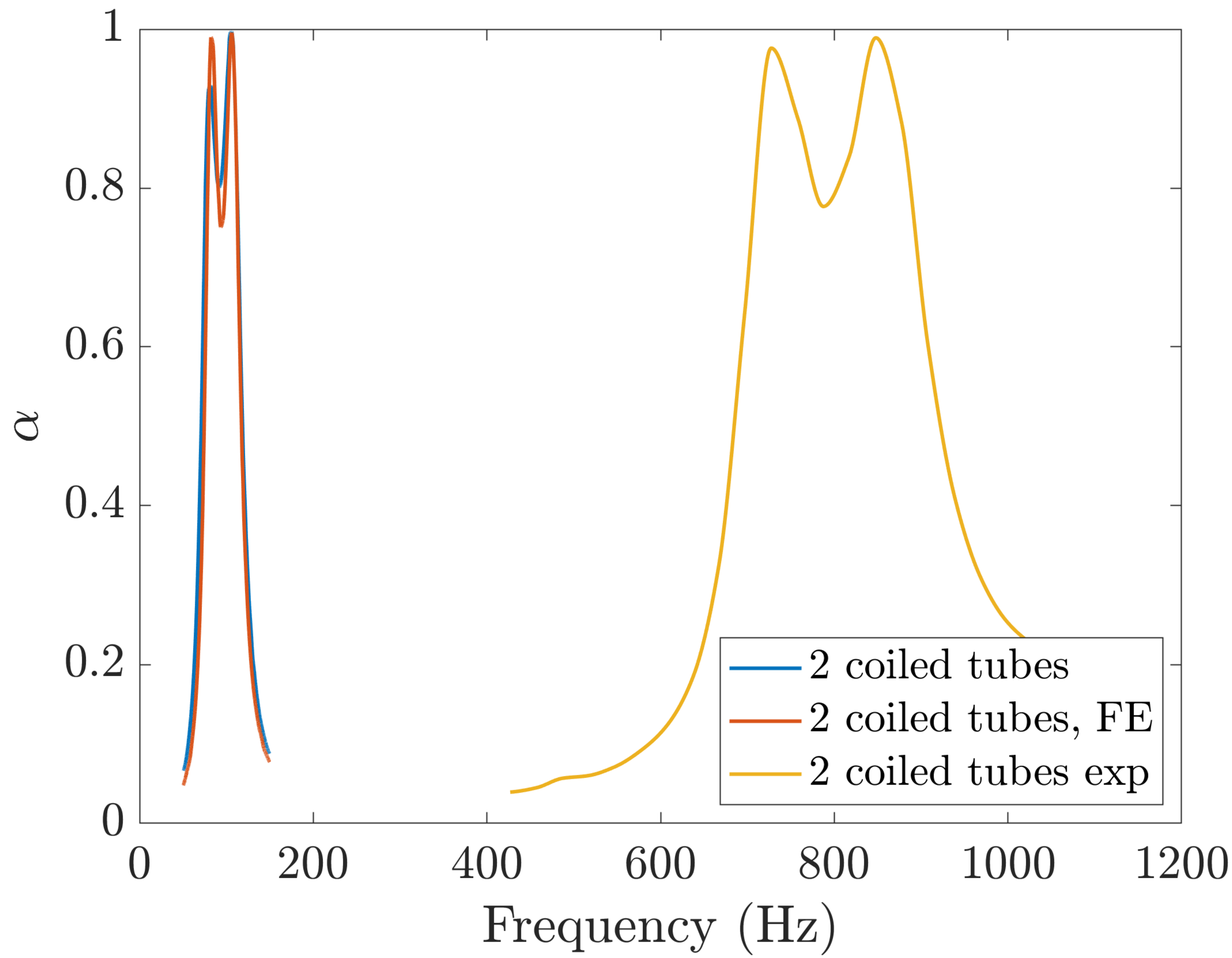
Perforated honeycomb-corrugation hybrid (PHCH)



Existing absorbers

C. Chen, Z. Du, G. Hu, J. Yang, A low-frequency sound absorbing material with subwavelength thickness, Applied Physics Letters 110 (22).

Axially coupled coiled tubes



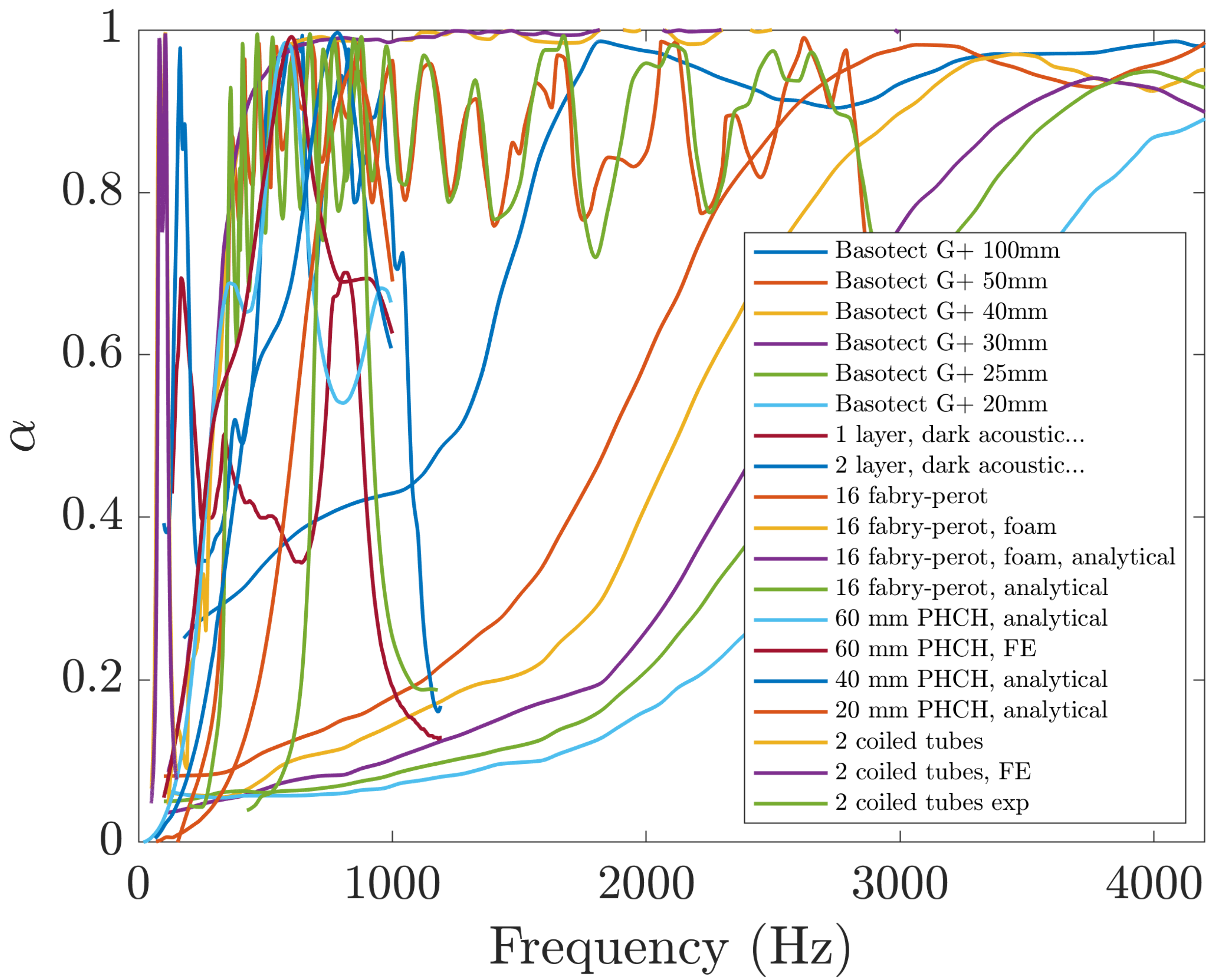
Existing absorbers

How can we compare absorbers?

Design for:

- Target frequency range
- Given space constraints

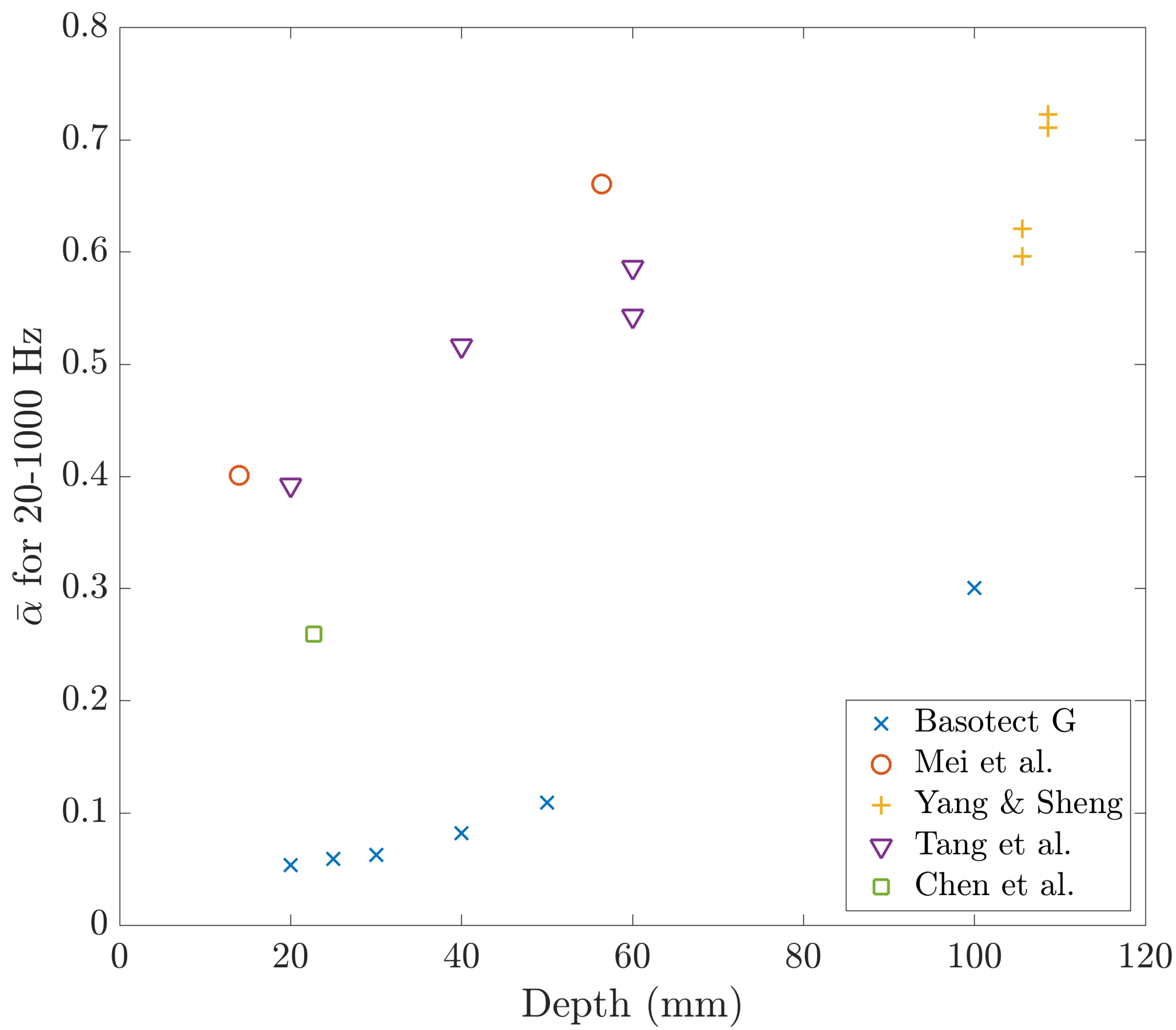
Space constraints are normally depth constraints



Average absorption against depth

Find the mean absorption in a target range and plot against depth of the absorber

$$\bar{\alpha}_{f_1\text{-}f_2} = \frac{1}{f_2 - f_1} \int_{f_1}^{f_2} \alpha \, \mathrm{d}f$$

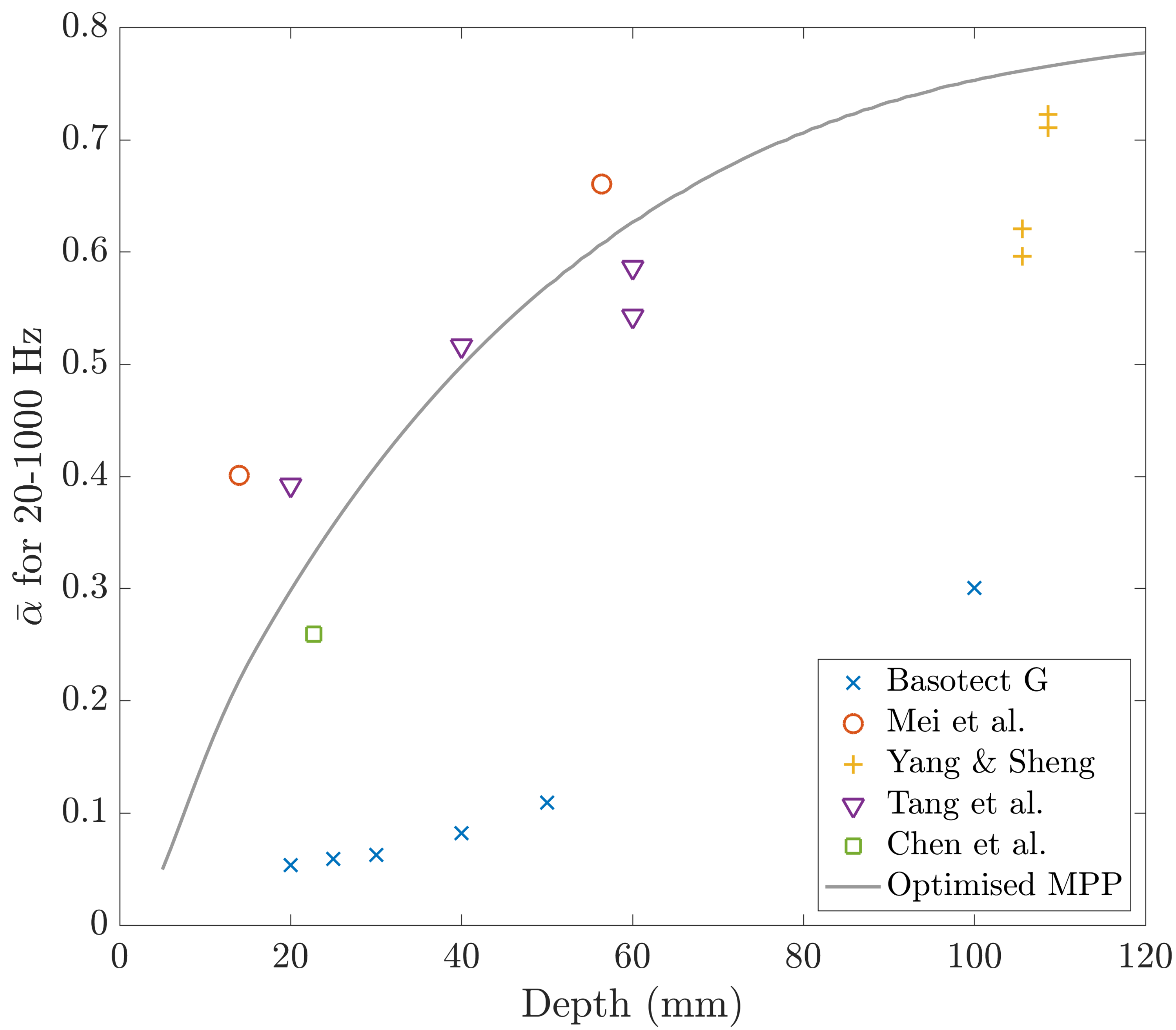


Average absorption against depth

Where we have an analytic expression of absorption we use gradient descent to optimise the parameters for a given absorber depth

Grey line shows the result of the optimisation for a micro perforated panel (MPP)

Minimum perforate diameter limited to 0.1 mm



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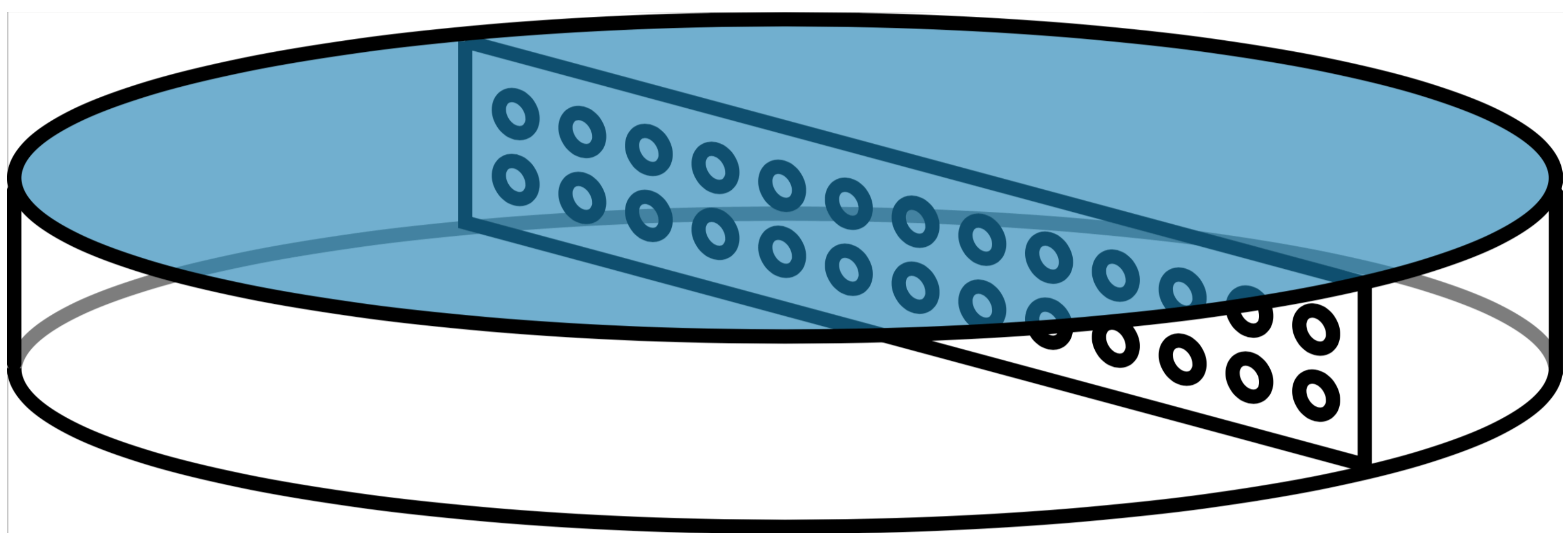
Segmented membrane sound absorber (SeMSA)



Two membranes coupled by a micro perforated panel

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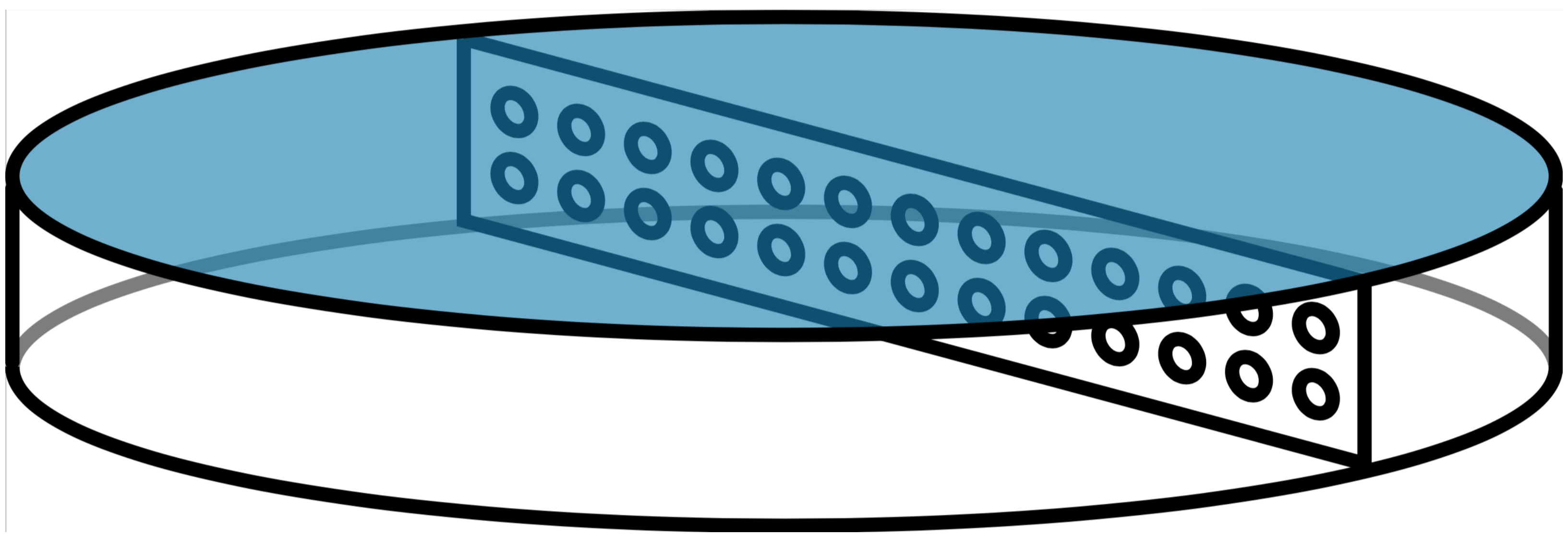
Segmented membrane sound absorber (SeMSA)



Two limp membranes coupled by a micro perforated panel

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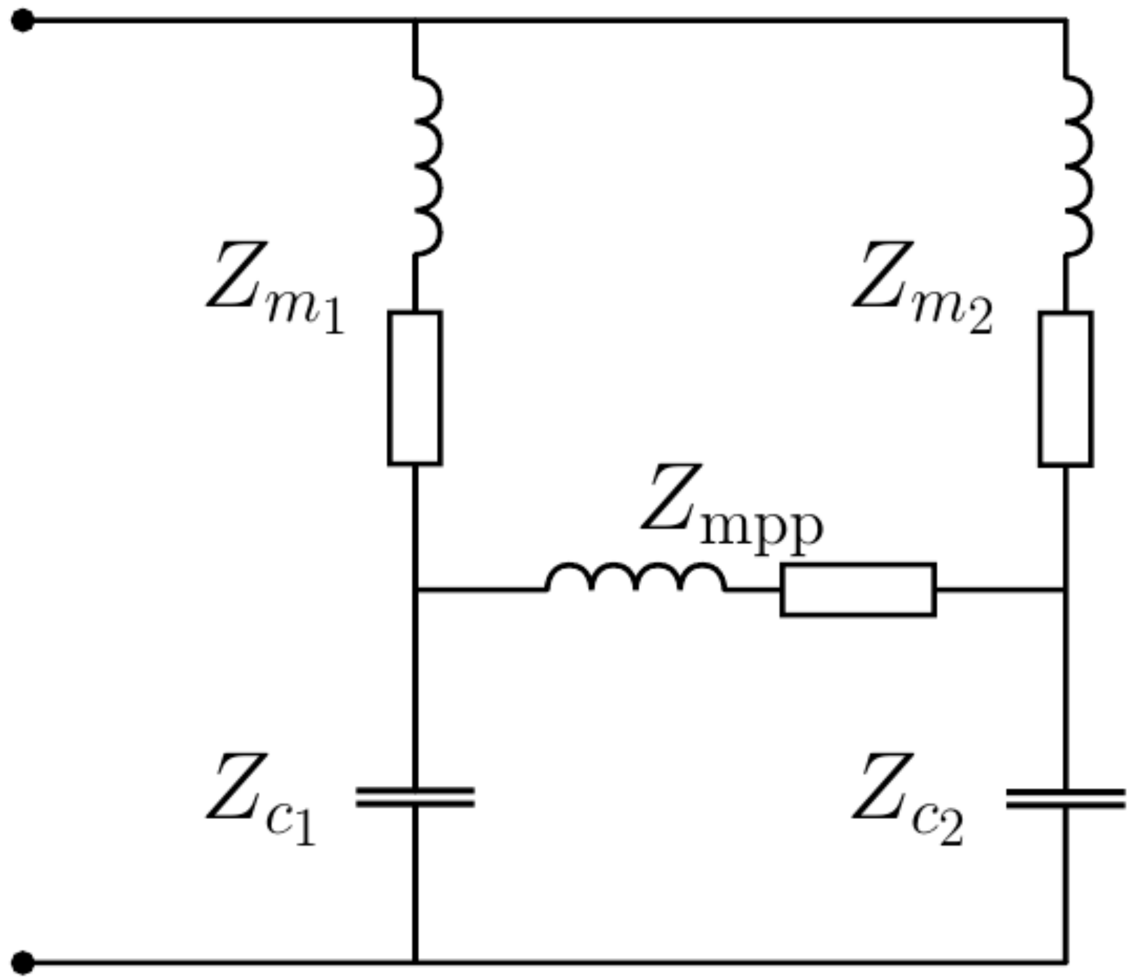
Equivalent circuit model



J. Carbajo, J. Ramis, L. Godinho, P. Amado-Mendes, Perforated panel absorbers with micro-perforated partitions, Applied Acoustics 149 (2019) 108-113.

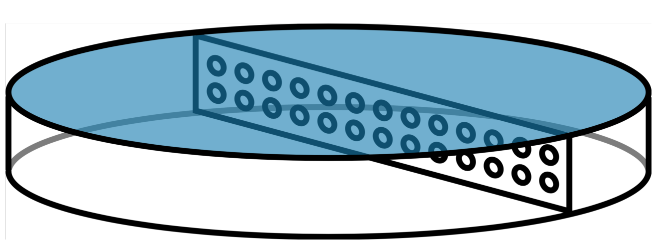
J. Merhaut, Theory of Electroacoustics, Advanced book program, McGraw- Hill International Book Company, 1981.

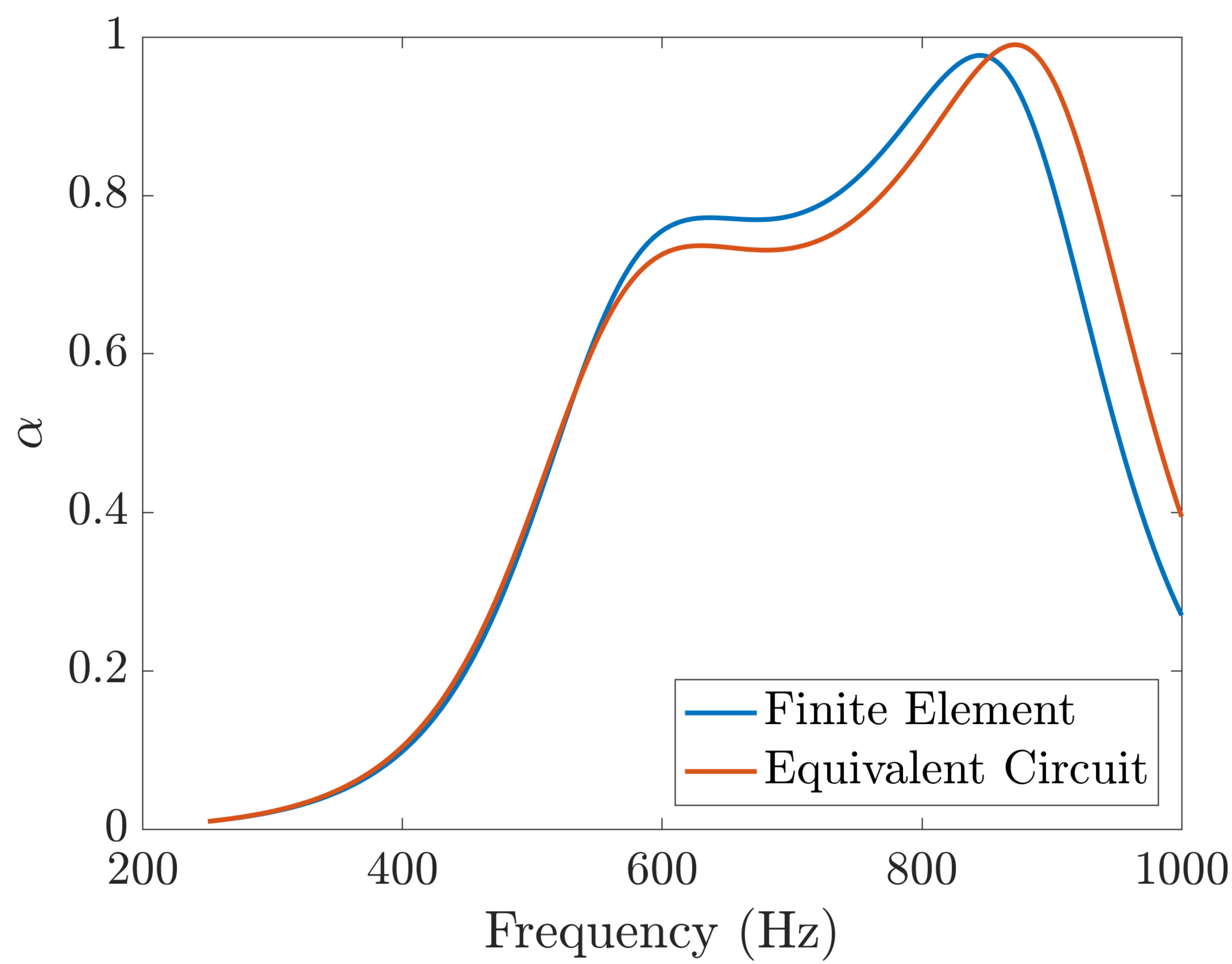
Validation of equivalent circuit against Comsol

MPP modelled using interior perforated plate boundary condition

Thermoviscous acoustics model of individual perforates also agrees

Membrane modelled using Comsol's membrane interface





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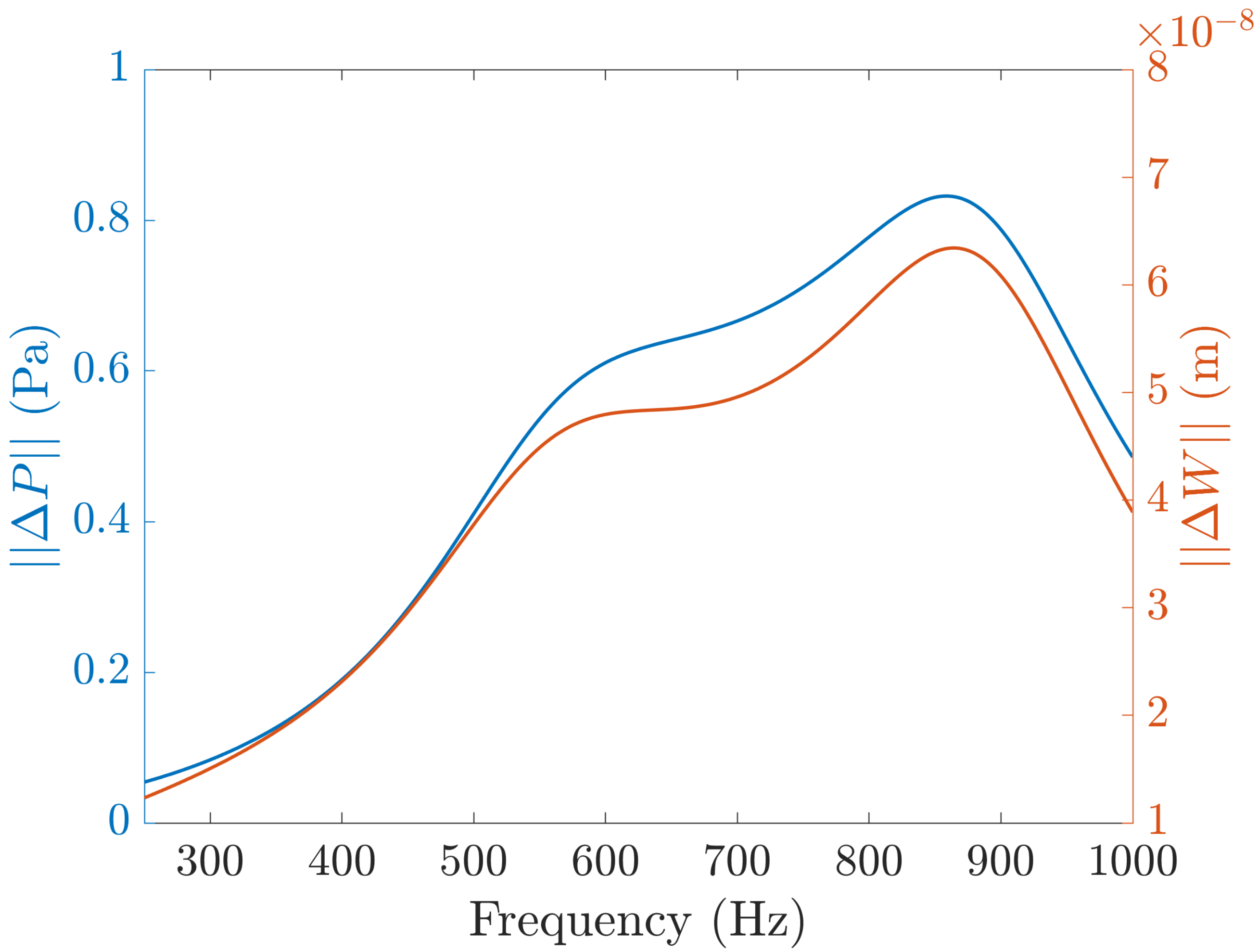
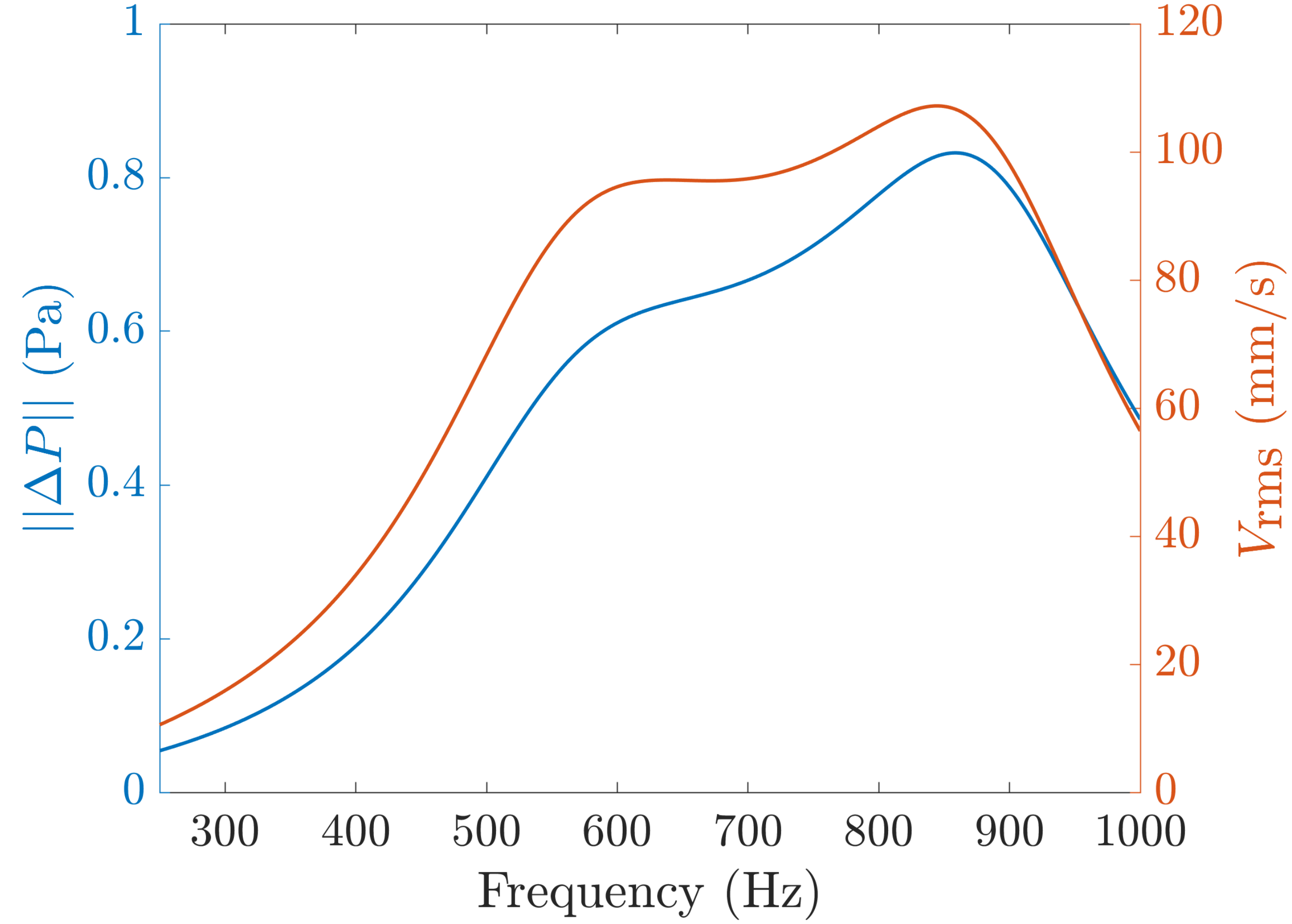
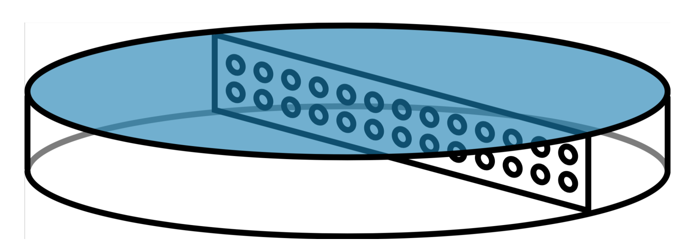
Mechanism





Difference in membrane displacements looks like pressure difference across MPP looks like velocity through MPP looks like… absorption

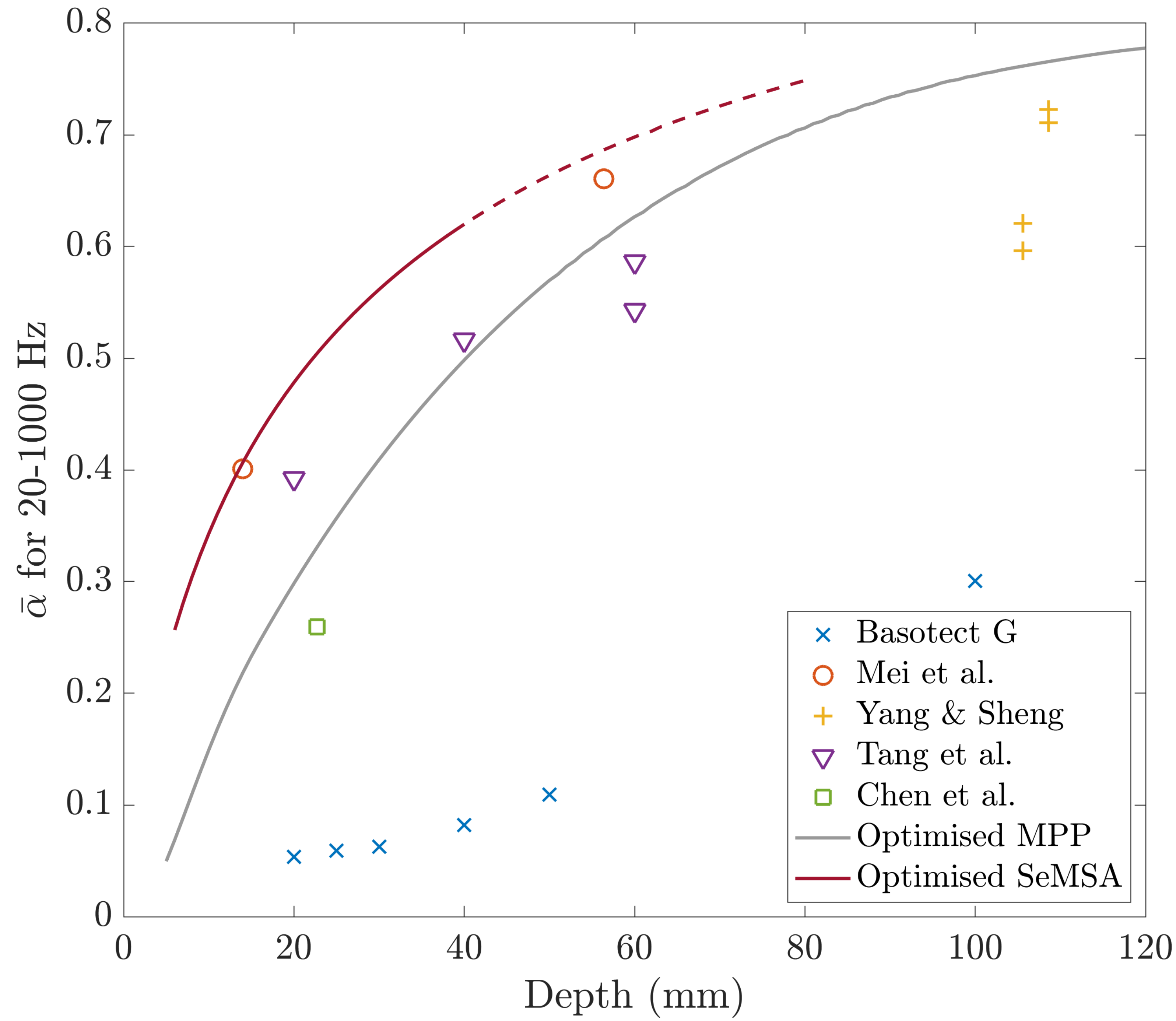


Applying the optimisation to SeMSA

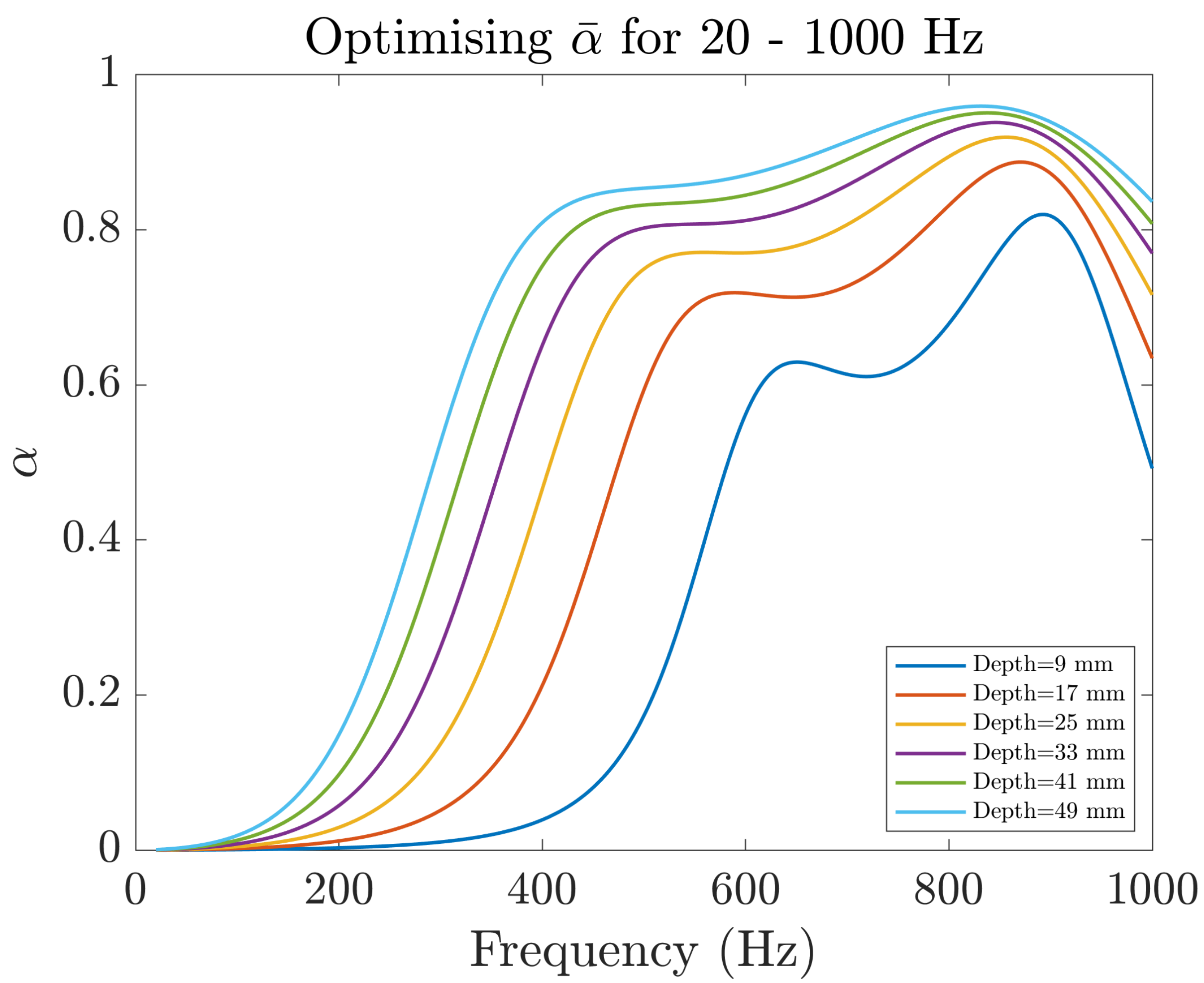
Use gradient descent to optimise the equivalent circuit model by maximising the average absorption cost function

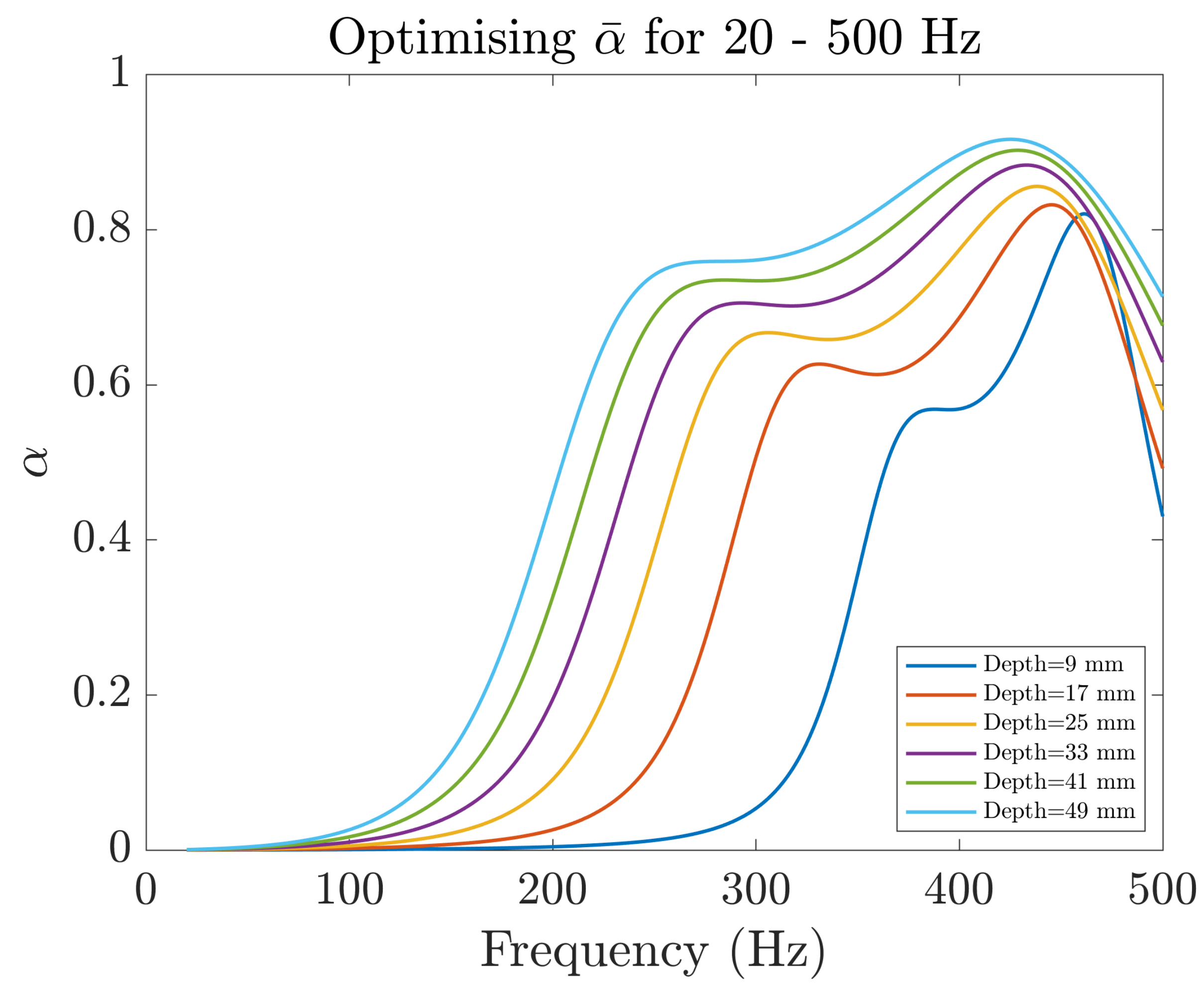
Lumped element modelling requires ka<<1

For 1000 Hz ka=1 when a=55 mm



Applying the optimisation to SeMSA





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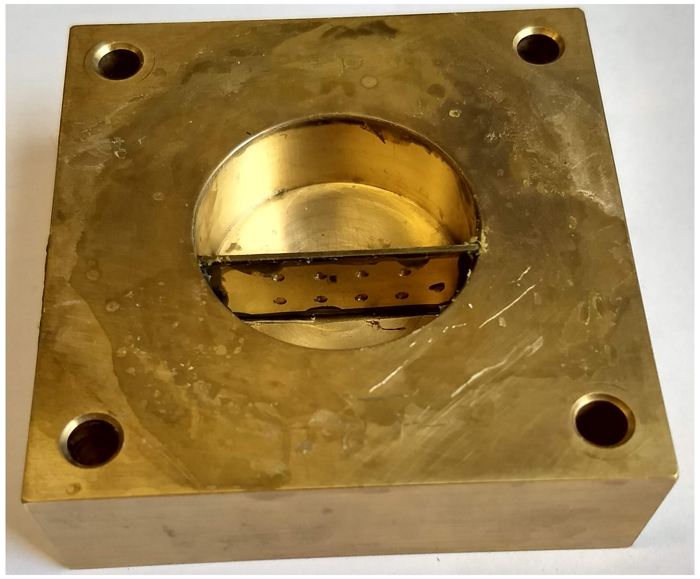
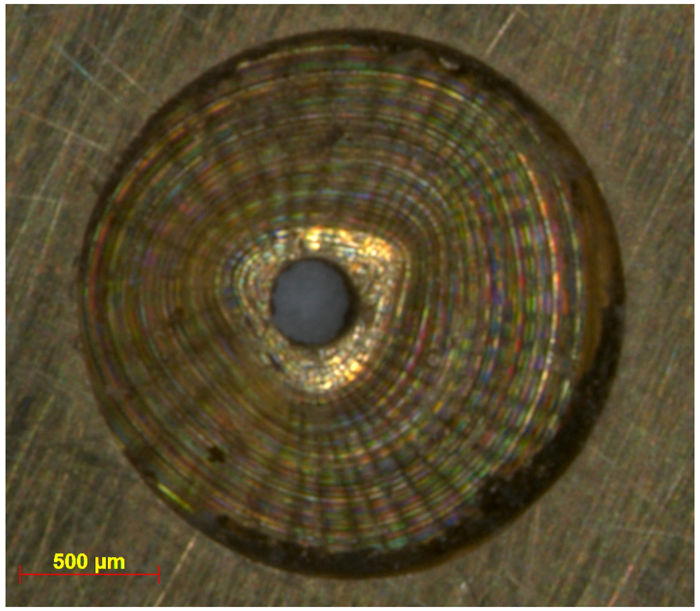
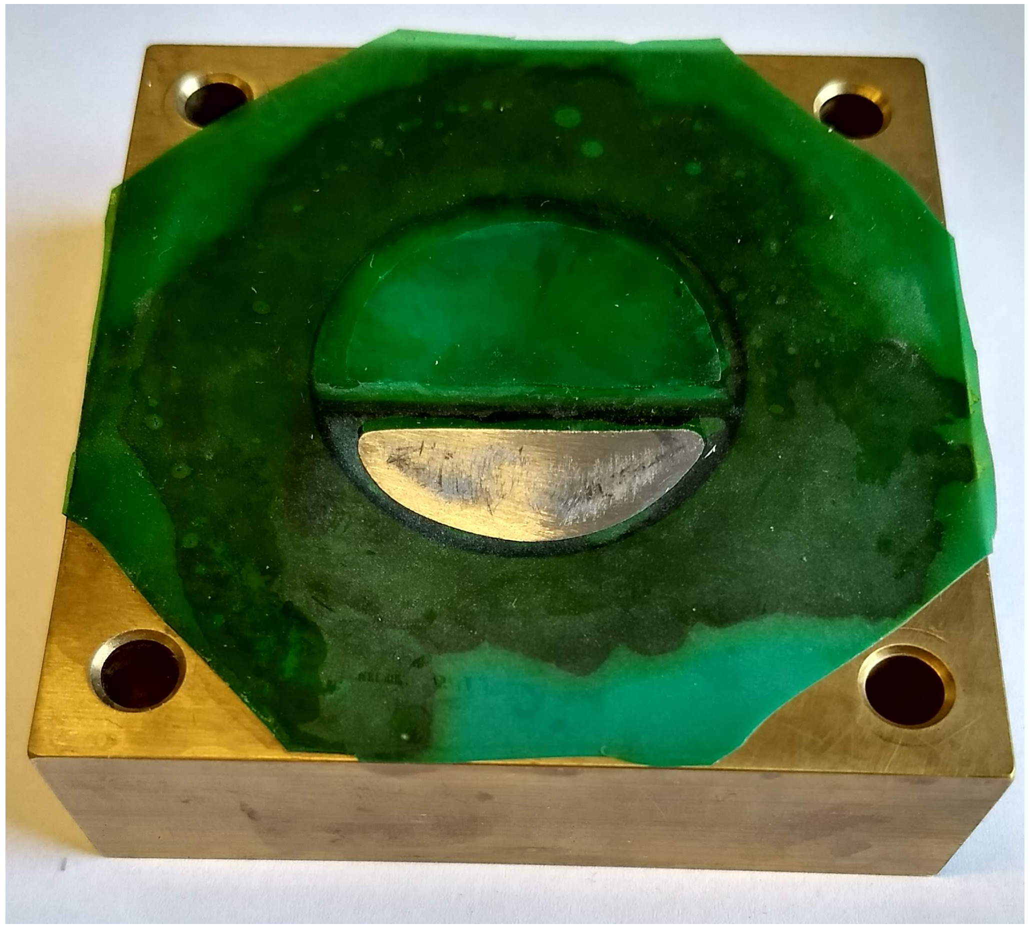
SeMSA prototype







- 15 mm deep cell
- Circular cell cut into brass block
- Bolts on to end of impedance tube
- MPP made from drilled brass plate
- Latex membrane
- Steel and layers of latex added for M1 and M2

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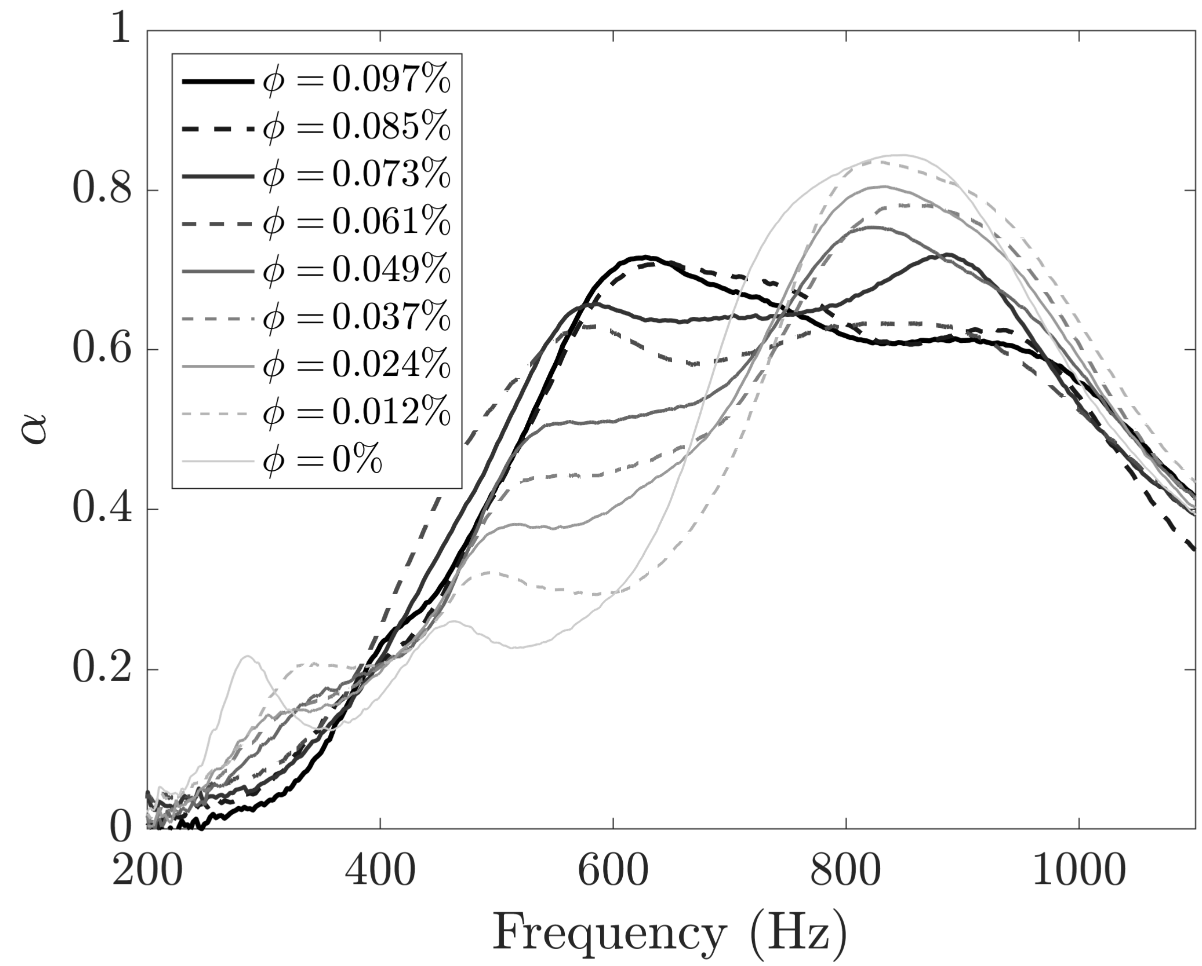
Experimental results

Results from cell shown in previous slide tested in a normal incidence impedance tube

Phi is the plate porosity which is varied by blocking hole with blu tack

From dark to light lines the MPP becomes more blocked and the absorption curve gradually changes to two uncoupled membrane-cavity systems



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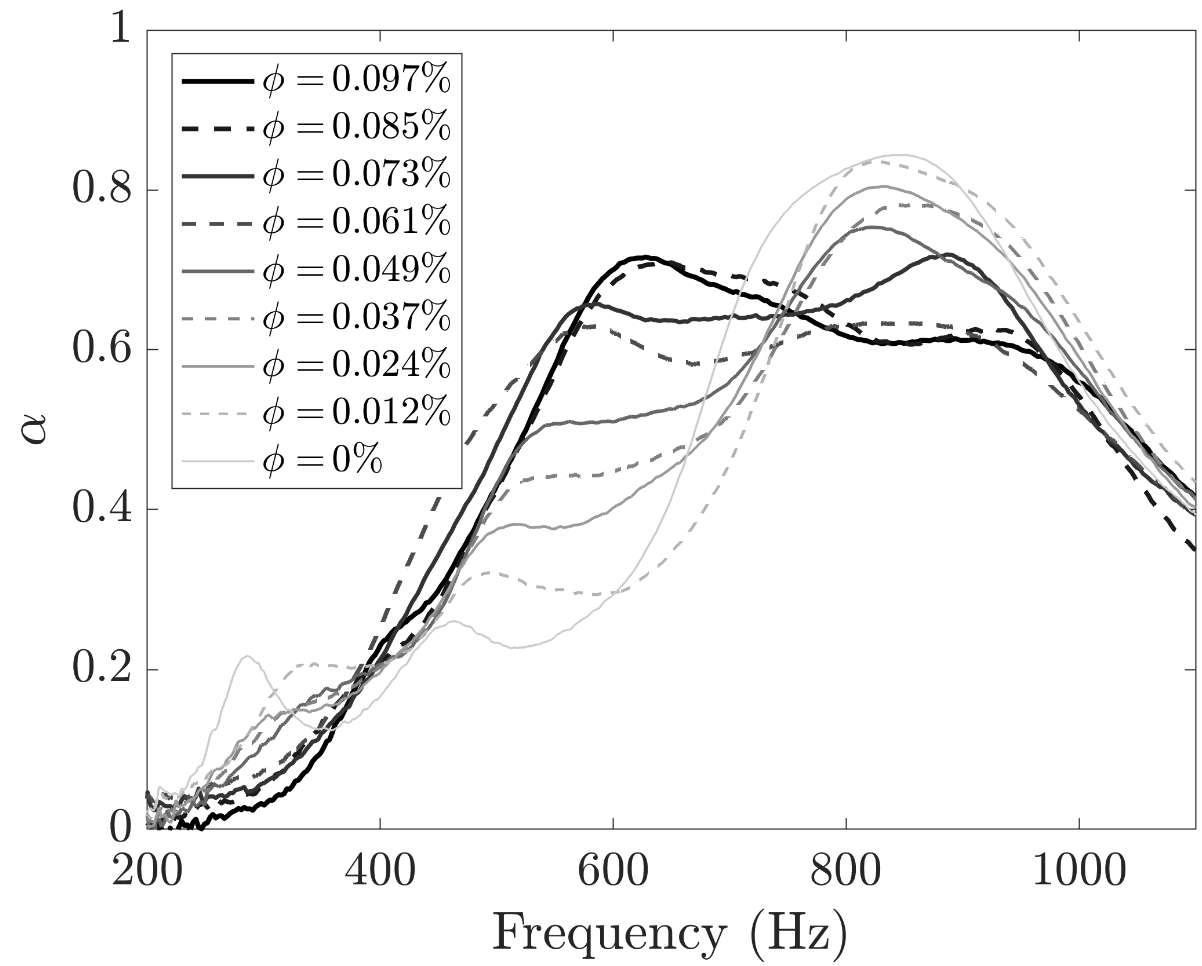

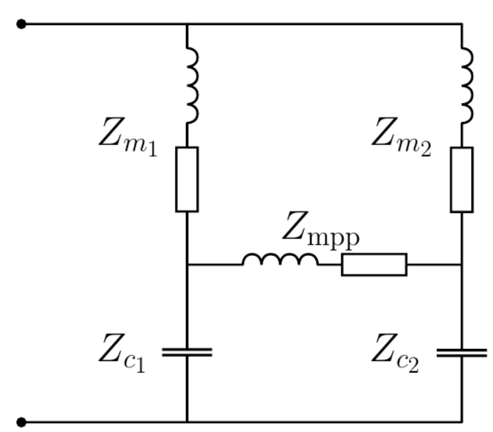

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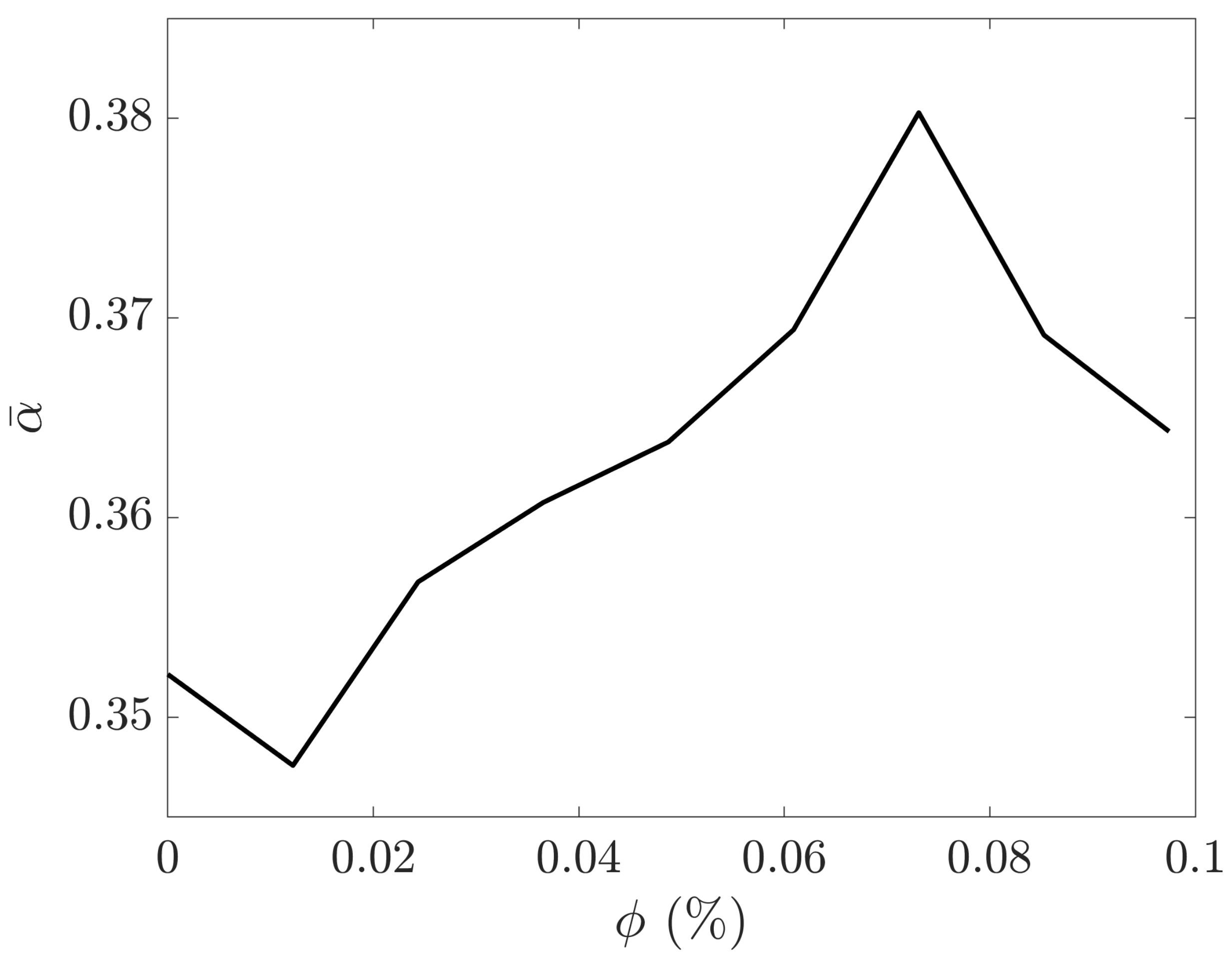
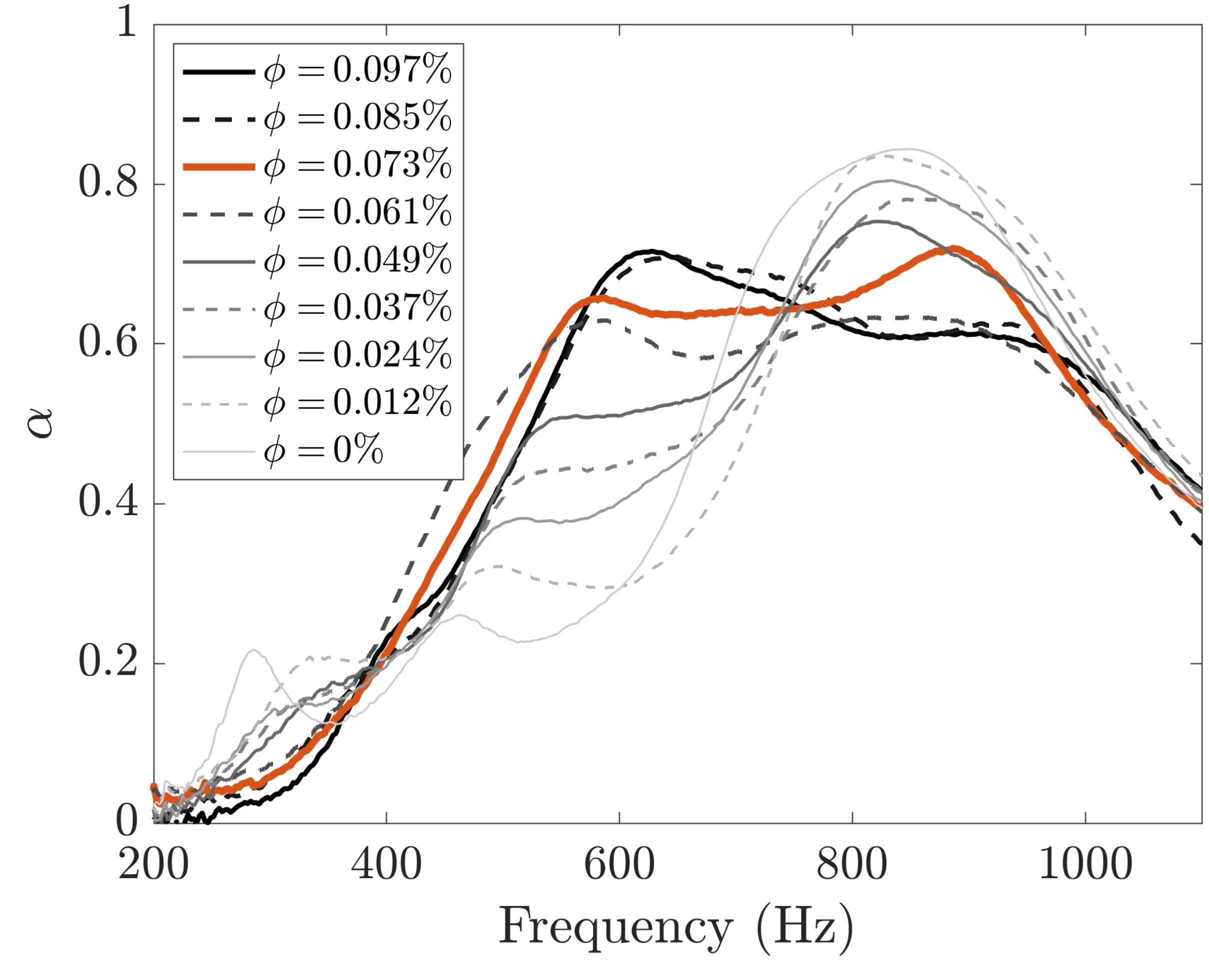
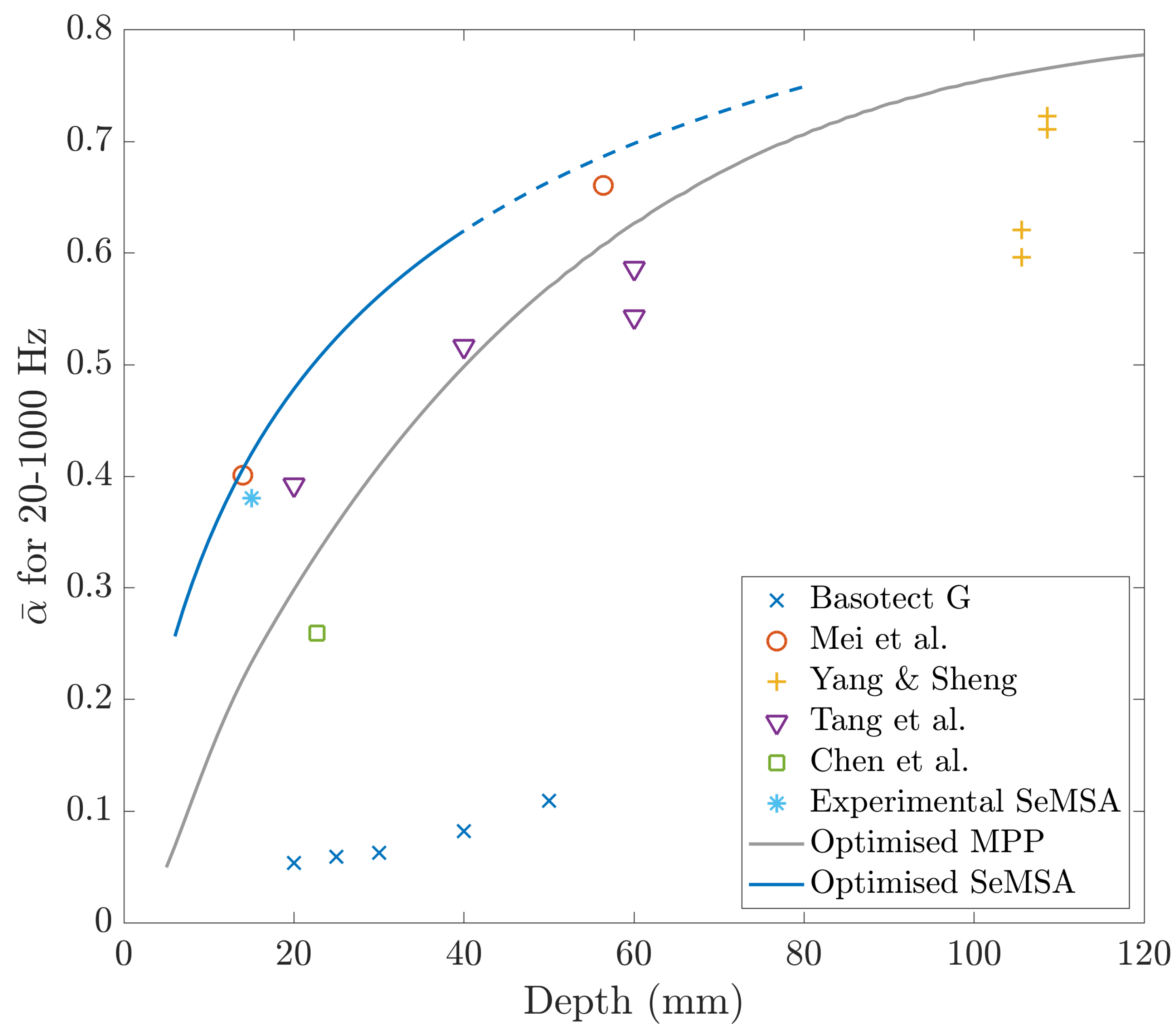
Experimental results





Average absorption is maximised when two holes are blocked

Experimental results



Average absorption lies slightly below optimisation curve because membrane damping was unknown in optimisation

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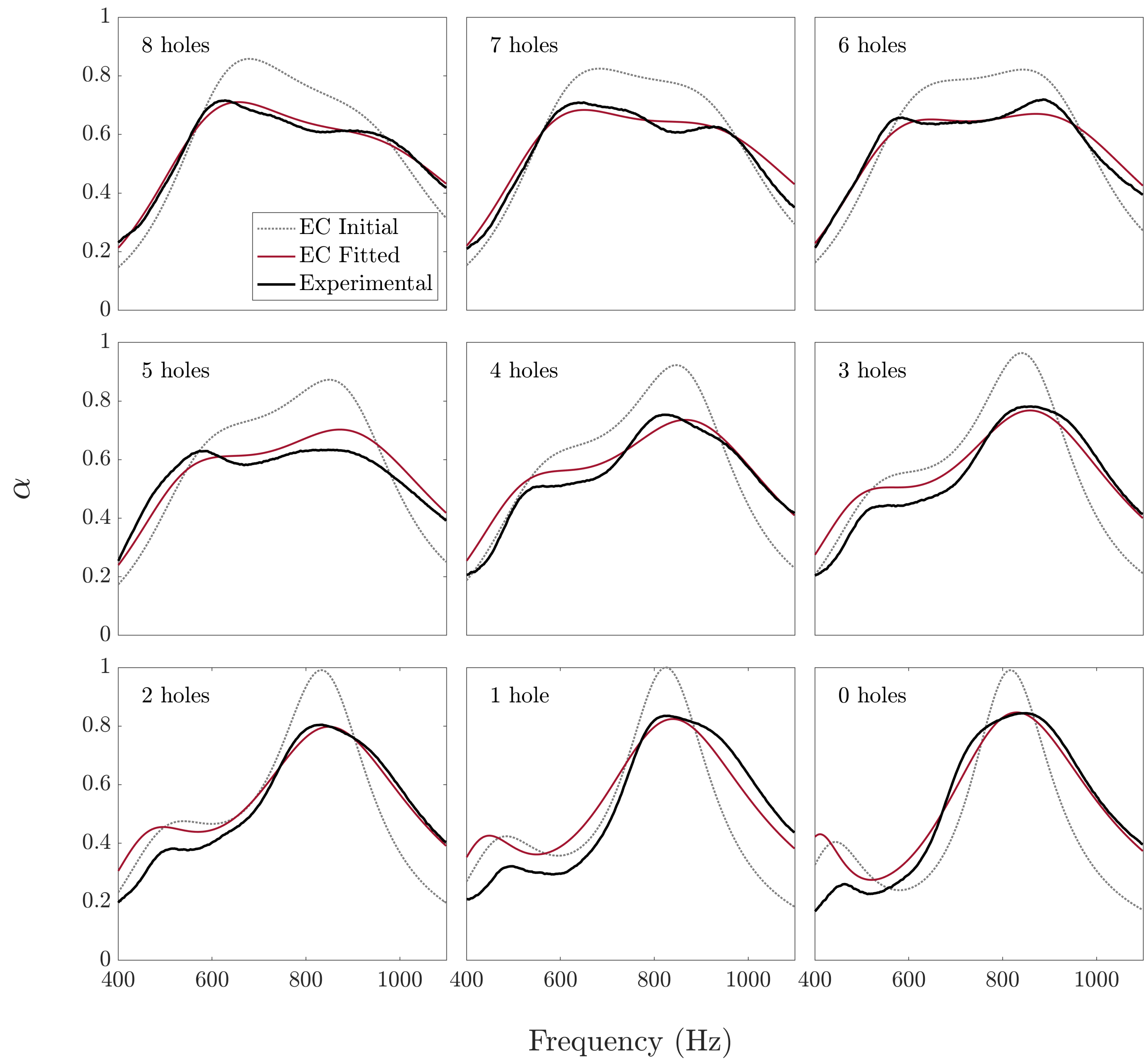
Fitting the results



Fit the model to the experimental results by minimising the sum of squared error between the model and experiment

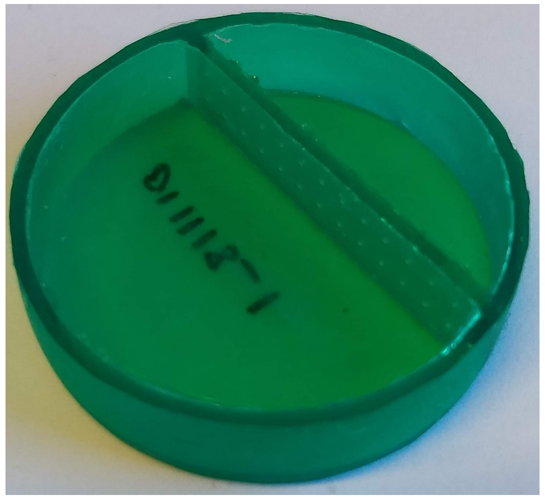
Grey line shows the model for the nominal parameters given by the optimisation

Red line shows the fitted curves

Only allow parameters to vary by +-5% except for membrane damping which is found by fitting process

To do

- Find a way to reliably predict membrane damping for inclusion in optimisation
- Experiment with manufacturing processes
- Test in oblique and grazing incidence
- Experiment with multiple chambers



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Thank you

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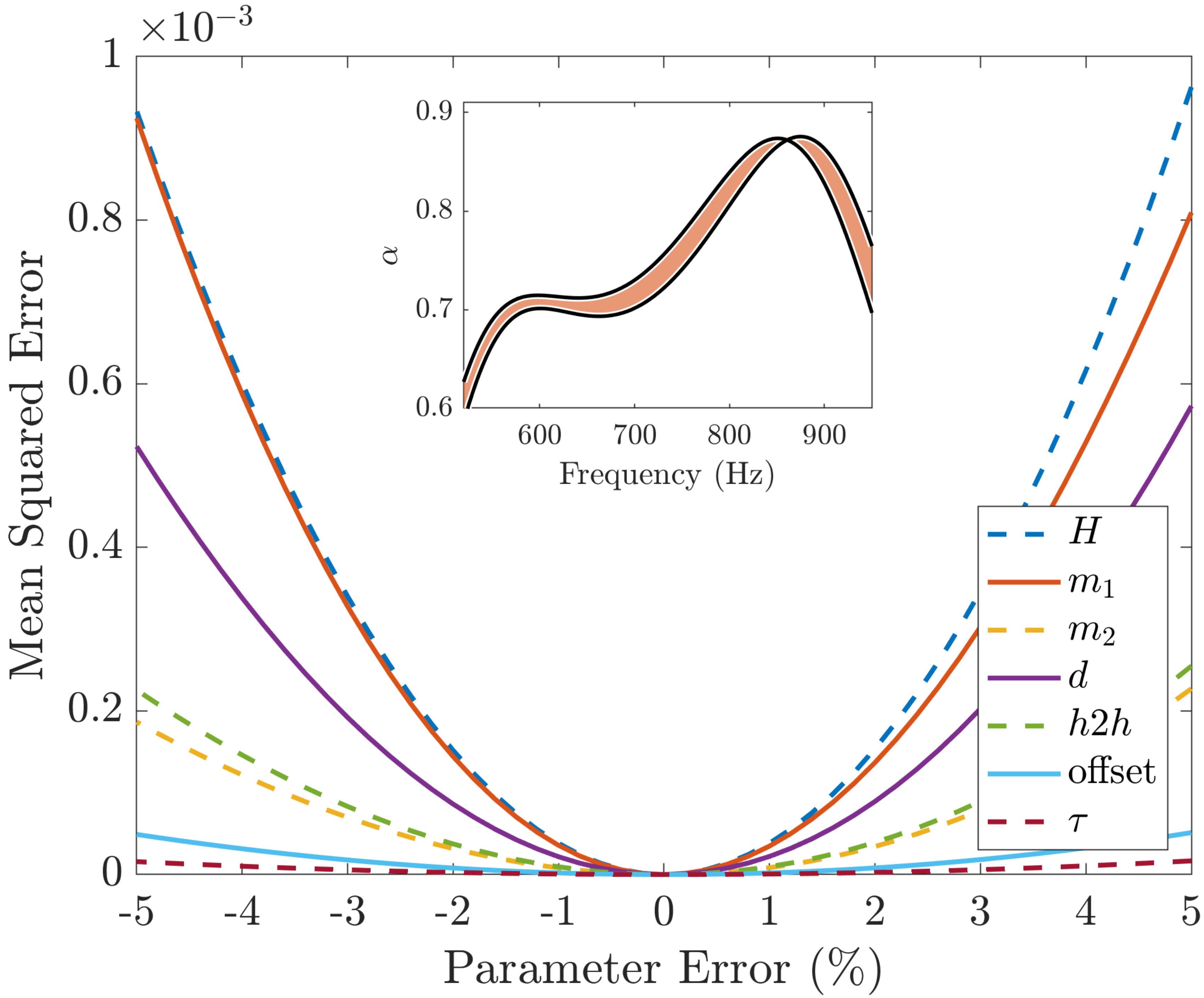
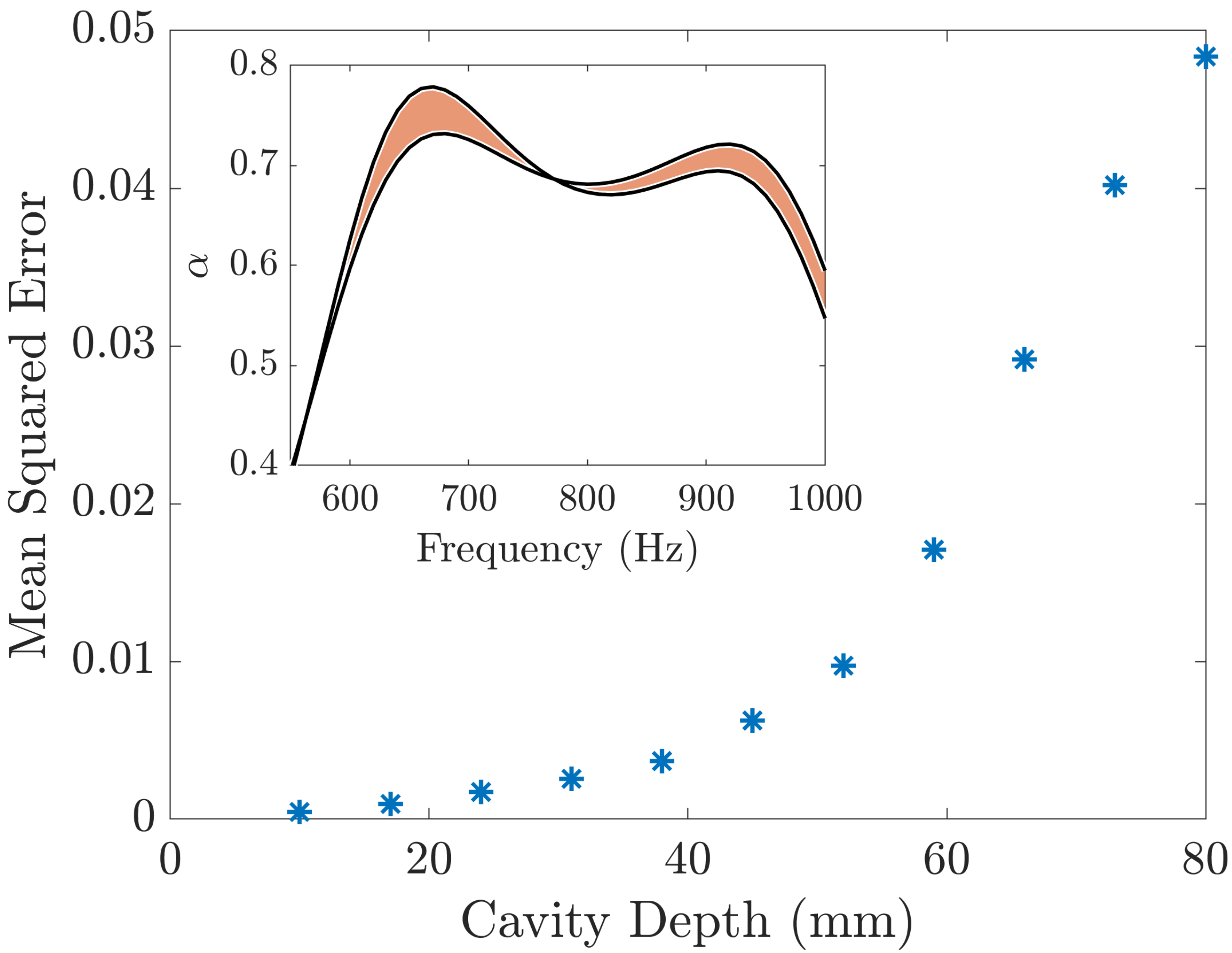
Sensitivity



Comsol vs EC



Mean squared error between EC and Comsol calculated for optimal parameters at different cavity depths

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How can we compare different absorbers?