RAINBOW TRAPPING ABSORBERS

Broadband and perfect absorption in subwavelenth panels

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Abstract

Perfect, broadband and asymmetric sound absorption is theoretically, numerically and experimentally reported by using subwavelength thickness panels in a transmission problem. The panels are composed of a periodic array of varying cross-section waveguides, each of them being loaded by an array of Helmholtz resonators (HRs) with graded dimensions. The low cut-off frequency of the absorption band is fixed by the resonance frequency of the deepest HR, that reduces drastically the transmission. The preceding HR is designed with a slightly higher resonance frequency with a geometry that allows the impedance matching to the surrounding medium. Therefore, reflection vanishes and the structure is critically coupled. This results in perfect sound absorption at a single frequency. We report perfect absorption at 300 Hz for a structure whose thickness is 40 times smaller than the wavelength. Moreover, this process is repeated by adding HRs to the waveguide, each of them with a higher resonance frequency than the preceding one. Using this frequency cascade effect, we report quasi-perfect sound absorption over almost two frequency octaves ranging from 300 to 1000 Hz for a panel composed of 9 resonators with a total thickness of 11 cm, i.e., 10 times smaller than the wavelength at 300 Hz.

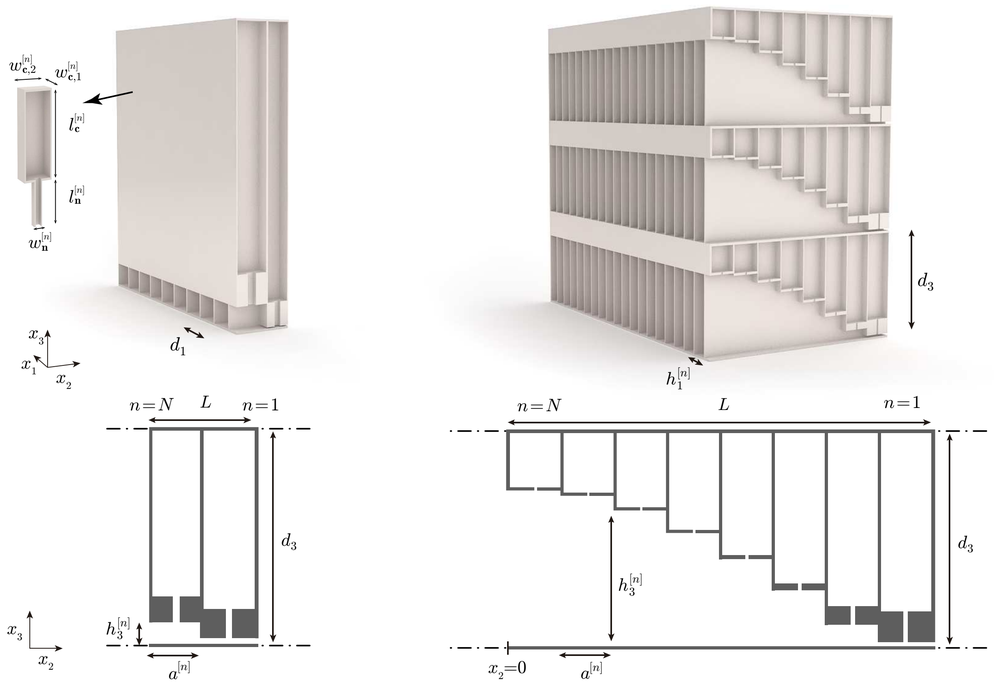
The structures

Goal: to design perfect absorbing panels based in metamaterials for transmission problems

Description: panels are composed of a periodic set of waveguides, of variying crossection. Each waveguide section is loaded by a Helmholtz resonator.

[A] Subwavelegth Asymetric Panel
Monocromatic perfect absorber ($\lambda/40$)

[B] Rainbow Trapping Absorber
Broadband perfect absorber ($\lambda/10$)



Methods

Transfer matrix method (TMM)

- Relates the pressure and velocity at the begining and at the end of the waveguide

$$\begin{bmatrix} p \\ v_x \end{bmatrix}_{x=0} = \mathbf{T} \begin{bmatrix} p \\ v_x \end{bmatrix}_{x=L} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} p \\ v_x \end{bmatrix}_{x=L}, \quad (1)$$

where $\mathbf{T}$ is given by the product of the transfer matrices of the N different cross-section waveguides loaded by HRs,

$$\mathbf{T} = \mathbf{M}_{\Delta l_{\text{slit}}}^{[1]} \prod_{n=1}^{N} \mathbf{M}_{\mathbf{s}}^{[n]} \mathbf{M}_{\text{HR}}^{[n]} \mathbf{M}_{\mathbf{s}}^{[n]} \mathbf{M}_{\Delta l_{\text{slit}}}^{[n+1]}. \quad (2)$$

Finite Element Method (FEM)

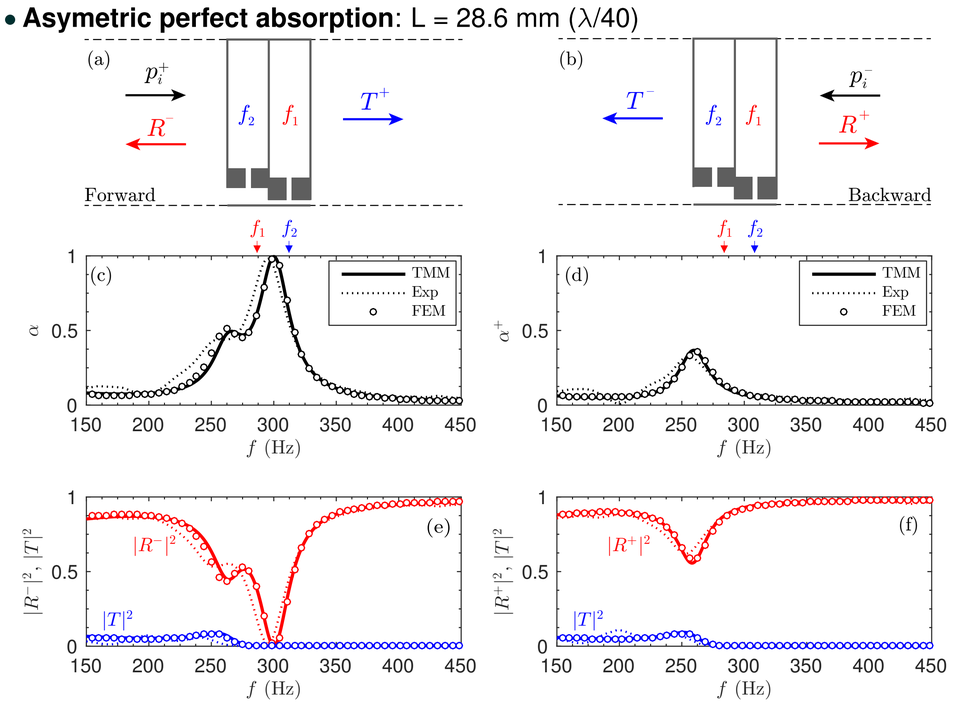
- COMSOL Multiphysics 5.2$^{\text{TM}}$.
- Thermo-viscous losses were accounted for by using the effective parameters of the air in the ducts

Measurements and sample design

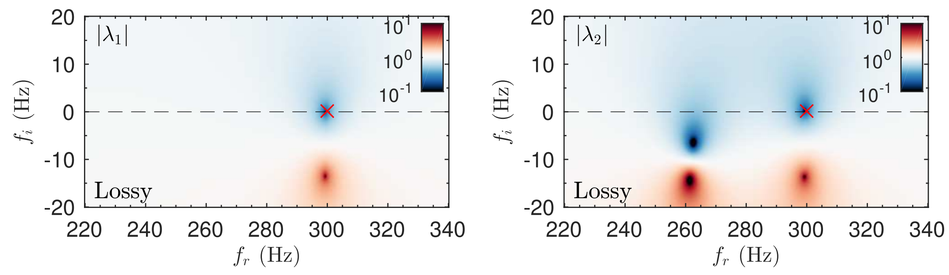
- 3D printed : stereo-lithography technique, photosensitive epoxy polymer (Accura 60®).
- Standard measures of transmission, reflection and absorption in a impedance tube with squared cross-section (15 cm side)

[A] Subwavelength Asymetric Panel

- **Asymetric perfect absorption**: L = 28.6 mm ($\lambda/40$)

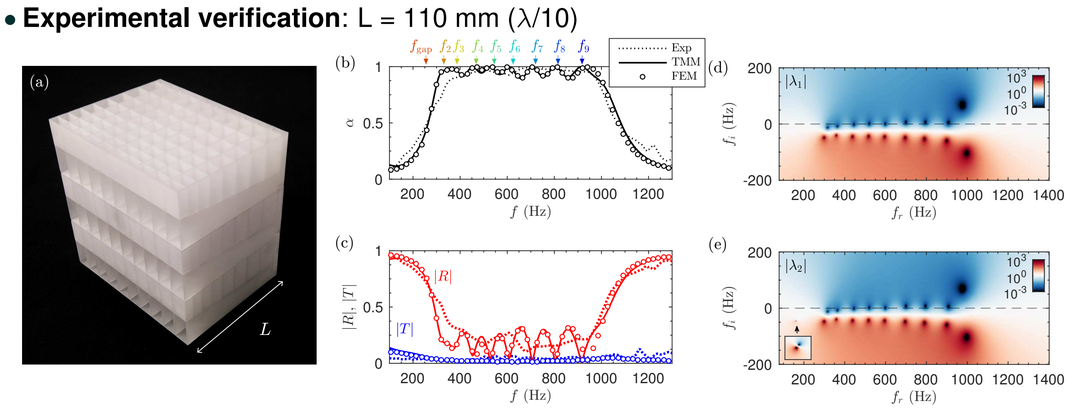


- **Analysis in the complex frequency plane**

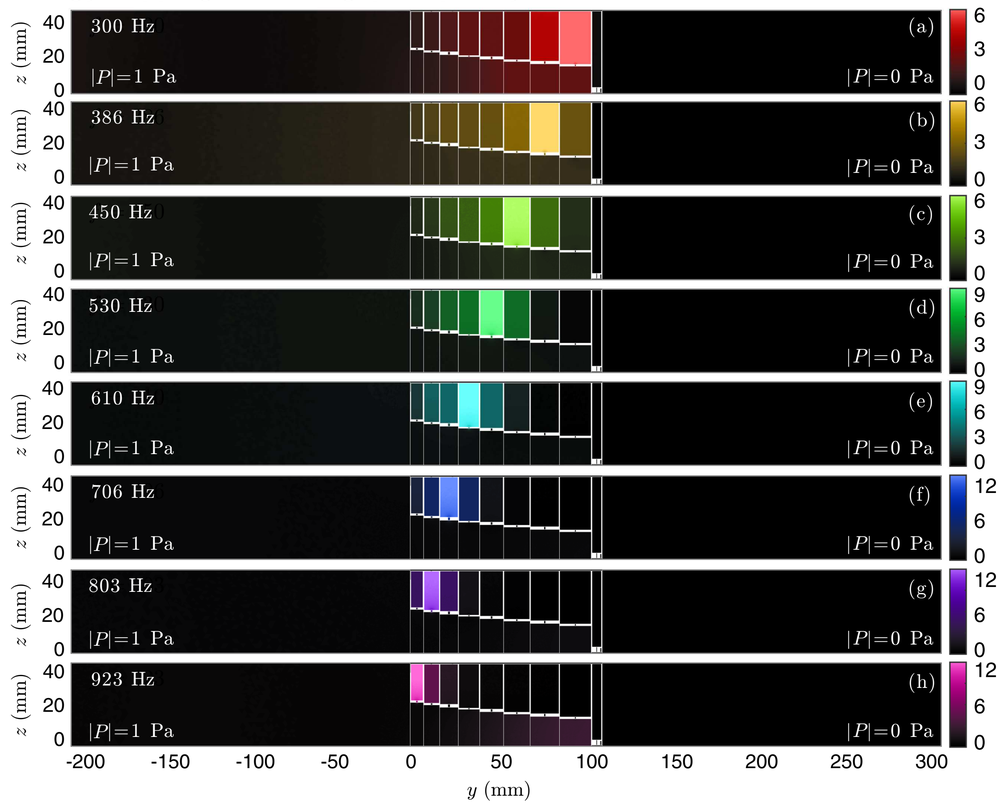


[B] Rainbow Trapping Absorber

- **Experimental verification**: L = 110 mm ($\lambda/10$)



- **Energy trapping and bandgap frequency cascade**



References

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Conclusions

Conditions for broadband perfect absorption in tranmission problem:

- The zeros of both eigenvalues of the scattering matrix must be located on the real frequency axis,
- The zeros of both eigenvalues must be at same frequencies,
- The quality factor of the resonances must be low to overlap in frequency.