Tortuous metamaterial for perfect sound absorption in transmission

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Introduction

Background

Using metamaterials, **degenerate modes** composed of two resonances can be generated: one **monopolar and one dipolar**. In this situation, the transmission and reflection in the structure can be reduced, thus achieving perfect absorption of the incident sound wave at that frequency. This behavior is usually observed at selected frequencies [2-4], and it becomes difficult to design a highly-porous and ventilated absorbing material exhibiting this behavior over a broad bandwidth.

Our proposal

In this work we designed a ventilated rigid panel based on tortuous channels to obtain broadband and perfect absorption using degenerate modes. ventilation.

Methods

When sound waves propagate through a porous material, its effective sound speed can be reduced due to the tortuous path. For this purpose, a periodic system composed of a par of narrow slits of different tortuosity has been designed, each channel presenting a different effective length. A degenerate mode is produced by overlapping a monopolar resonance from one slit, and a dipolar mode from the other. Therefore, by tuning the tortuosity we couple **monopolar and dipolar Fabry-Perot modes** of each channel to produce a chain of degenerate modes, resulting in **perfect sound absorption**.

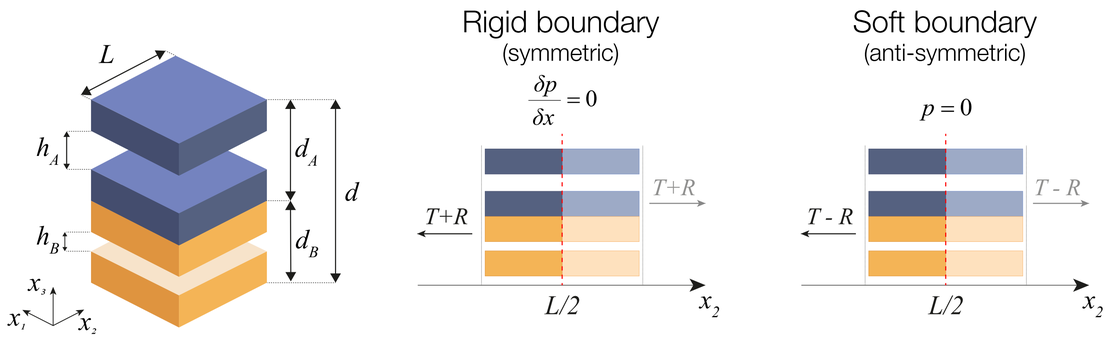
Transfer matrix method (TMM) for a fluid layer

The effective properties of each slot are modelled by means of a total transfer matrix [1], including thermovoiscous losses by using effective parameters. The transmission matrix of a fluid layer takes the form

$$\begin{bmatrix} p \\ V_x \end{bmatrix}_{x=0} = \mathbf{T} \begin{bmatrix} p \\ V_x \end{bmatrix}_{x=L} \qquad \mathbf{T} = \begin{bmatrix} \cos\left(k_f L\right) & iZ'_f \sin\left(k_f L\right) \\ i\dfrac{1}{Z'_f} \sin\left(k_f L\right) & \cos\left(k_f L\right) \end{bmatrix}$$

Parallel element transfer matrix decomposition

When dealing with a symmetric system we can decompose the problem into **two sub-problems** of reflection:

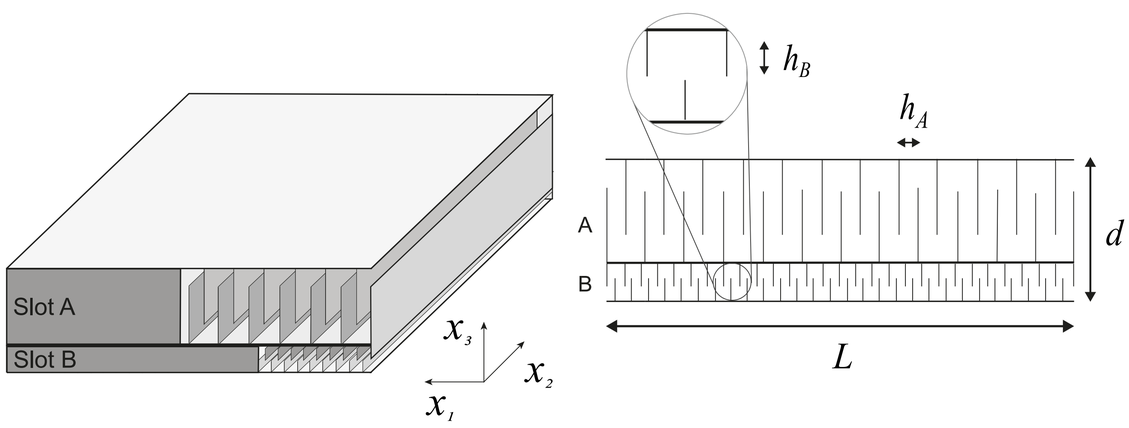


The complete problem for the structure composed of the two slots can be solved on the basis of the **reflection coefficients** of each sub-problem [2]:

$$R = \frac{R_s - R_a}{2} \qquad T = \frac{R_s + R_a}{2} \qquad \alpha = \frac{\alpha_s + \alpha_a}{2}$$

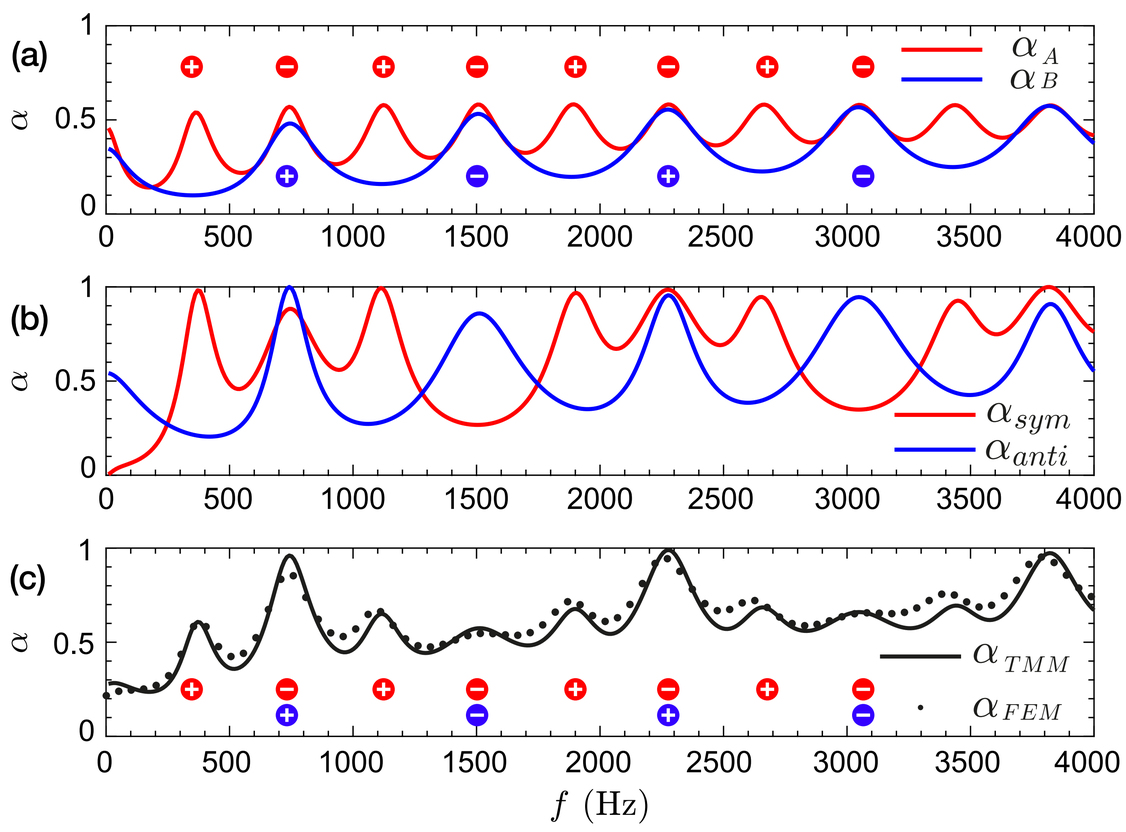
Metamaterial design

The material consists of a panel composed of two rigid material slots of **different effective lengths**. Obstacles are included to produce tune the propagation paths within each slot, resulting in different tortuosity.



Results

Having different lengths in each slot, the monopolar and dipolar absorption resonances of the whole structure are no longer staggered in frequency.



(a) The first monopolar mode on the slit A matches the second dipolar resonance of the slit B.

(b) This overlapping of resonances allows the tuning of the symmetric and antisymmetric subproblems to maximize absorption.

(c) When a monopolar and a dipolar resonance coincide on both slots, a degenerate mode is produced and both subproblems can be impedance-matched resulting in perfect absorption.

This behavior has been predicted using a TMM and by FEM simulations, showing a good agreement between theory and computations.

Conclusions

A system with a degenerate resonance produced by the existence of overlapping symmetric and antisymmetric modes in the subsystems formed by each slot has been designed. The proposed geometry giving rise to a high absorption coefficient over a broad bandwidth.

Impact

This type of solution might be of great interest for applications in ventilation problems, for example, for noise control in industrial engineering.

Next Steps

Construct the proposed material and measure it experimentally in an impedance tube in order to corroborate the results obtained.

References

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