Tortuous metamaterial for perfect sound absorption in transmission

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When resonators are included within a material, as in metamaterials, strong scattering and absorption phenomena occur, which can be used to design sound absorbers. Such phenomena have been explored to create very low-thickness, sub-wavelength absorbing structures [1, 2]. Using metamaterials, degenerate modes can be generated, for example, in a slotted rigid material with embedded resonators, and each degenerate mode is composed of two resonances: 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. However, this behavior is usually observed at selected frequencies [3-5], and it becomes difficult to design a highly-porous and ventilated absorbing material exhibiting this behavior over a broad bandwidth, for example, for noise control applications in acoustic engineering.

In this work we designed a ventilated rigid panel based on tortuous channels to obtain broadband and perfect absorption using degenerate modes. When sound waves propagate though a porous material, its sound speed can be reduced due to the tortuous path. Therefore, by tuning tortuosity we couple monopolar and dipolar Fabry-Perot modes of each channel to produce a chain of degenerate modes, resulting in perfect sound absorption. 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 (Fig 1 (a). A degenerate mode is produced by overlapping a monopolar resonance from one slit, and a dipolar mode from the other. The effective properties of each slot are modelled by means of the transfer matrix method [1]. The scattering produced by the panel is studied analytically through parallel element transfer matrix decomposition [3], allowing to separate the solution of the symmetric and antisymmetric problems. In addition, the structure is numerically simulated and measured using finite element simulation techniques (FEM).

By optimizing the geometry of the structure, we can obtain different effective lengths within each slot. As a result, the monopolar and dipolar resonances of the structure are no longer staggered in frequency. This process enables the shifting of resonance frequencies of the two slots, until the first monopolar mode on the slit A matches the second dipolar resonance of the slit B, see Fig 1. (c). This overlapping of resonance modes allows the tuning of the symmetric and antisymmetric subproblems, Fig. 1 (d). When a monopolar and a dipolar resonance frequency of both slots coincide, a degenerate mode is produced and both subproblems can be impedance-matched if they introduce the exact amount of thermoviscous losses. Under these conditions, we generate perfect absorption for the total problem, Fig. 1 (e). Note due to the weak dispersion at each slit this process is iteratively repeated for even harmonics of the first degenerate mode. This behavior has been predicted using a TMM and by FEM simulations, showing a good agreement between theory and computations.

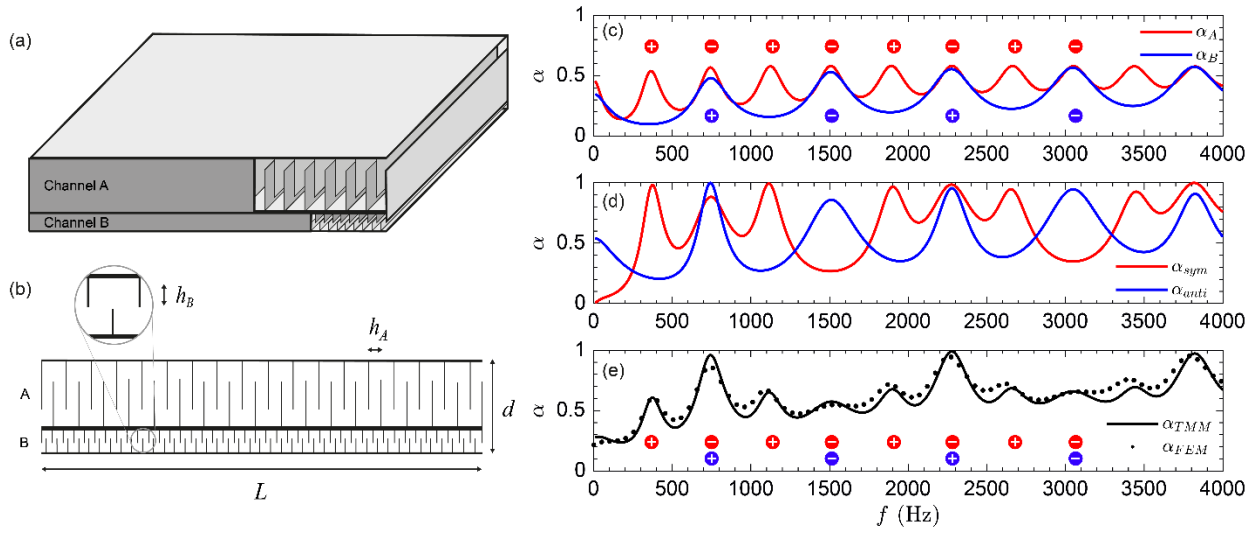


Fig. 1. (a,b) schematic representation of the unit cell of the panel perforated by two narrow slots. Slot A (top) and B (bottom) have effective lengths L_A, L_B and heights h_A, h_B respectively. (c) Graphical representation of the absorption of slots A (red) and B (blue) in which the modes of both slots are marked by positive and negative signs. (d) Absorption of the symmetric (red) and antisymmetric (blue) subproblems. (e) Absorption of the total problem by the analytical method by TMM (black) and by numerical method (markers). The markers through the graphs indicate the monopolar and dipolar resonances.

In this work, the physics behind the presence of degenerate modes in perforated materials with slots of different effective lengths has been reviewed. For this purpose, 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 absorption of the structure is studied theoretically and measured numerically. Considering the correction applied to the effective lengths of the slots for this geometry, values like those obtained through analytical predictions are shown. By optimizing the proposed geometry, a coupling of the symmetrical and antisymmetrical modes is achieved, giving rise to a high absorption coefficient over a broad bandwidth. This type of solution might be of great interest for applications in ventilation problems, for example, for noise control in industrial engineering. In addition, the physics on which the research is based gives the option to develop such systems with broad bandwidth.

References

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