# Experimental Evidences of Perfect Acoustic Absorption in Deep Sub-wavelength Structures for the Ventilation Problems.

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e-Forum Acusticum 2020
Dec 7-11, 2020

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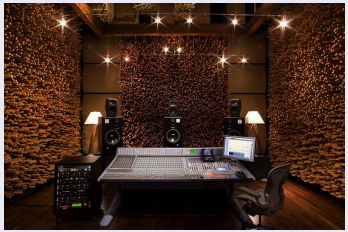
# Outline

1. Introduction
   - Motivation
   - Main ingredients
2. 1D Reciprocal scattering problem
   - General problem
   - Decomposition on symmetric and antisymmetric problems
3. Mirror symmetric resonator for ventilation problems
   - The main difficulty in ventilation problem
   - Configuration for the mirror symmetric resonator
   - Coupling each symmetry
   - Perfect absorption in symmetric ventilation problems
4. Conclusions

## Absorption



## Diffusion

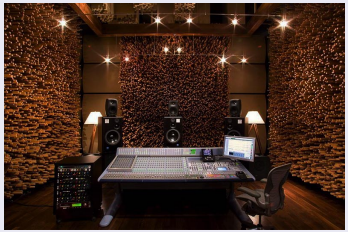


- Not efficient at low frequencies.

## Absorption



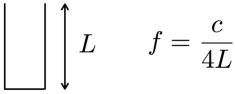
## Diffusion



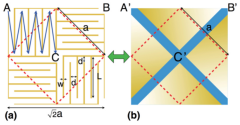
- Not efficient at low frequencies.

- Can we find subwavelength structures based on metamaterials to improve the behaviour of the exisitng systems for absorption and diffusion?
- Can we control the absorption of sound efficiently at low frequencies by using metamaterials?

- Shift down the resonance frequency of a system: Two possibilities

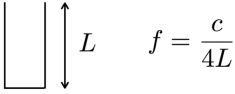



$$f = \frac{c}{4L}$$

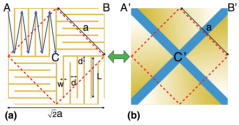



Phys. Rev. Lett. 108, 114301, 2012

- Shift down the resonance frequency of a system: Two possibilities

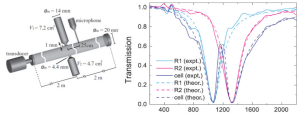



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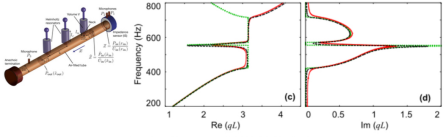



Phys. Rev. Lett. 108, 114301, 2012

- Tunability of the losses in the slow sound regime:

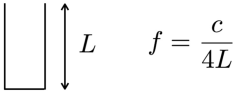



Phys. Rev. B 84, 064304 (2011)

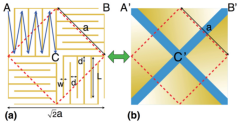



New J. Phys. 16, 093017 (2014)

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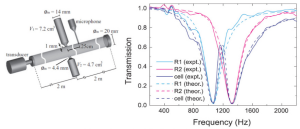



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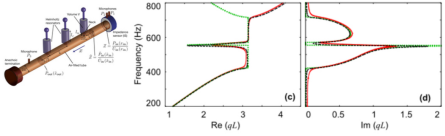



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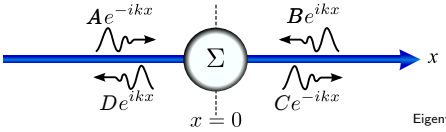



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- Critical coupling condition for impedance match the system.




$$\begin{bmatrix} C \\ B \end{bmatrix} = S(\omega) \begin{bmatrix} A \\ D \end{bmatrix} = \begin{bmatrix} T & R^- \\ R^+ & T \end{bmatrix} \begin{bmatrix} A \\ D \end{bmatrix}.$$

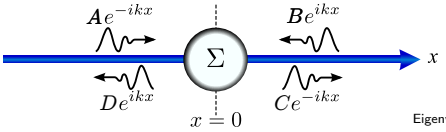
Eigenvalues:

$\lambda_{1,2}(\omega) = T(\omega) \pm \sqrt{R^-(\omega)R^+(\omega)}$.

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$\vec{x}_1(\omega) = \left(R^-(\omega), -\sqrt{R^-(\omega)R^+(\omega)}\right)$,

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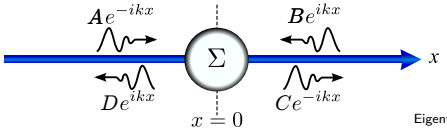



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- A zero eigenvalue of the S-matrix corresponds perfect absorption ($C = 0$, $B = 0$).
  Lossless case, temporal invariance $S(\omega)^* = S(\omega^*)^{-1}$.

- This happens at a frequency at which $T(\omega) = \pm\sqrt{R^-(\omega)R^+(\omega)}$ and when the incident waves ($A$,$D$) correspond to the relevant eigenvector.




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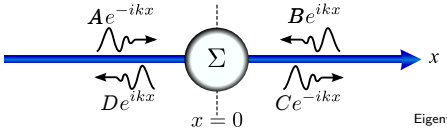
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**Reflection**

No transmission.
$S(\omega) = R(\omega) = B/A$.

N. Jiménez, APL (2016)




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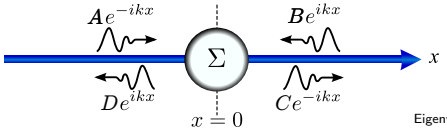
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N. Jiménez, APL (2016)

**Asymmetric resonator**

$R^+ \neq R^-$
$T(\omega) = \pm\sqrt{R^-(\omega)R^+(\omega)}$

N. Jiménez, APL (2017)




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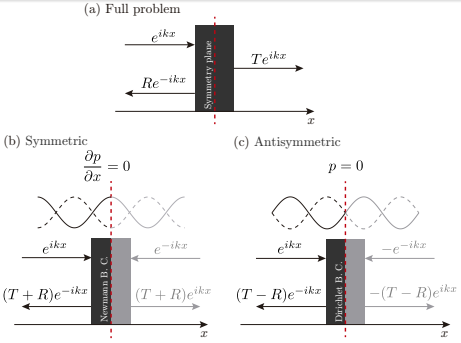
**Symmetric resonator**

$R^+ = R^- = R$
$T(\omega) = \pm R(\omega)$

V. Romero-García, PRApplied, (2020)

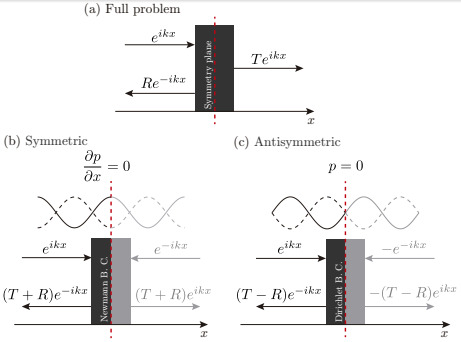
$$S(\omega) = \begin{bmatrix} T & R \\ R & T \end{bmatrix}$$

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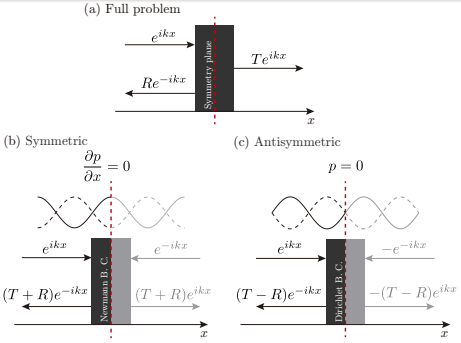



**Symmetric problem, Neumann BC at $x = 0$**

$R_s = R + T, \qquad \alpha_s \equiv 1 - |R_s|^2,$
$\lambda_1 = R_s.$

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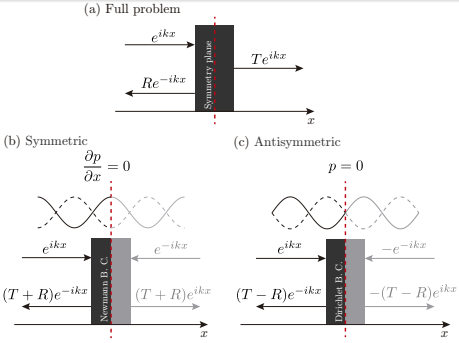
$R_s = R + T, \qquad \alpha_s \equiv 1 - |R_s|^2,$
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**Antisymmetric problem, Dirichlet BC at $x = 0$**

$R_a = R - T, \qquad \alpha_a \equiv 1 - |R_a|^2,$
$\lambda_2 = R_a.$

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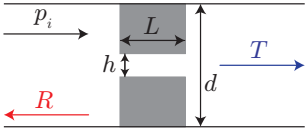
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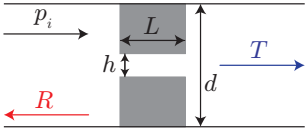
$$R = \frac{R_s + R_a}{2}, \qquad T = \frac{R_s - R_a}{2}, \quad \textit{and} \quad \alpha = \frac{\alpha_s + \alpha_a}{2}.$$

Achieving $\alpha = 1$ at a given frequency needs to simultaneously obtain $R_s = R_a = 0$ [or $\alpha_s = \alpha_a = 1$] of the two sub-problems.



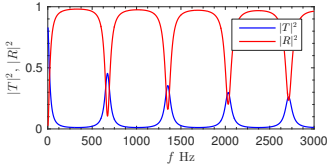

$h = 3.8$ mm, $L = 25$ cm, $d = 15$ cm

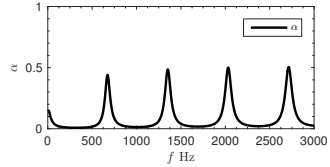
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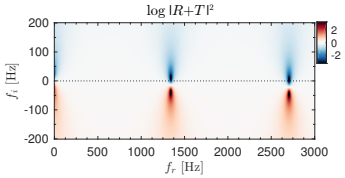


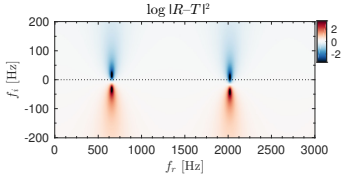

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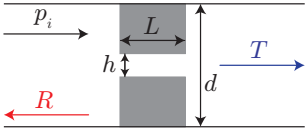
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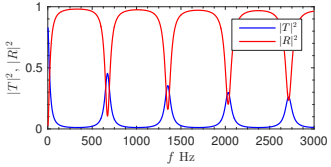



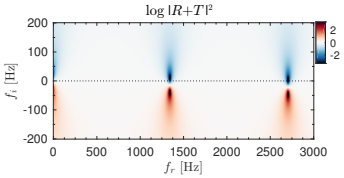



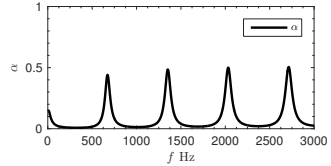


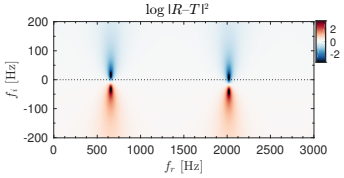

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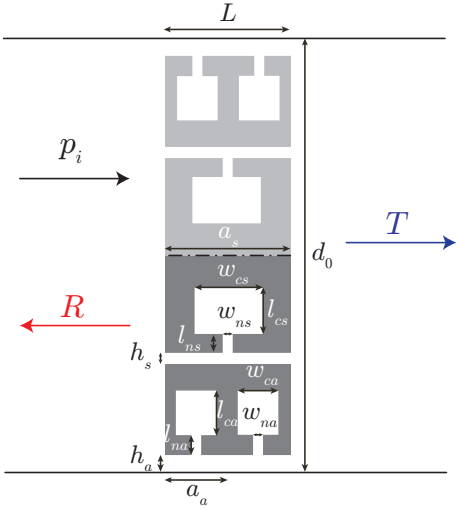


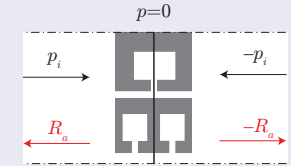



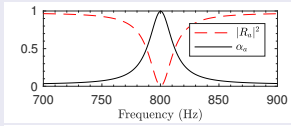

$$\alpha = (\alpha_s + \alpha_a)/2, \qquad \text{so} \qquad \alpha_{max} \geq 0.5.$$

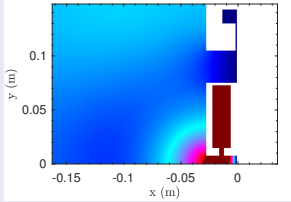



- Resonator made of a symmetric and an anti-symmetric building blocks.
  - The symmetric block:
    1 single symmetric resonance.
  - The anti-symmetric block:
    1 symmetric and 1 antisymmetric resonance.
- Losses are accounted for in the duct and HR elements (Stinson, 1991).
- Correction lengths are accounted for in the HR and duct elements.
- Coupling between slits are accounted for by the Bloch modes in the exterior medium.

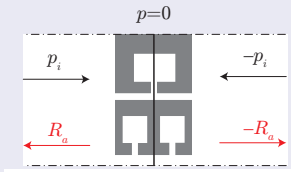
## Antisymmetric resonator

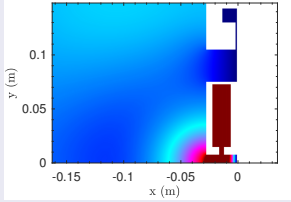


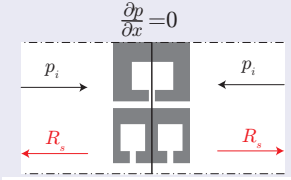



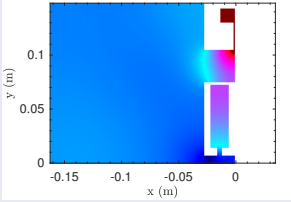
## Antisymmetric resonator



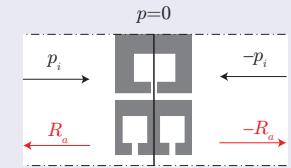




## Symmetric resonator

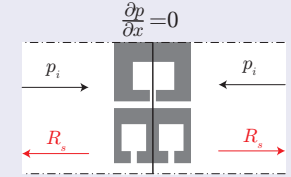


## Antisymmetric resonator

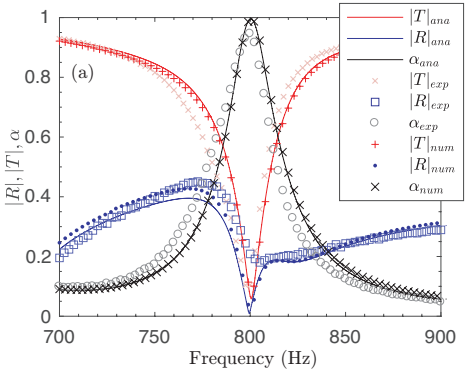


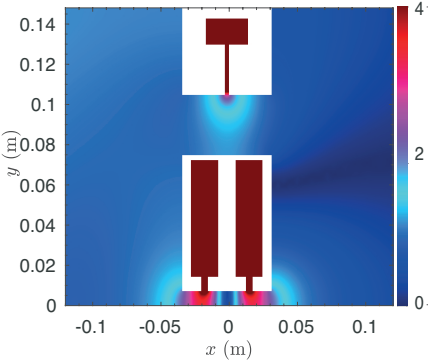

## Symmetric resonator




## Fabrication

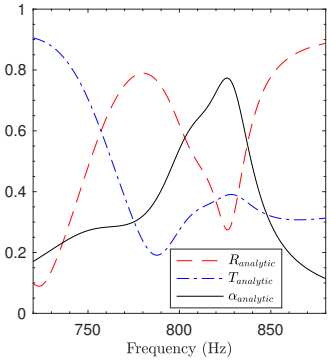


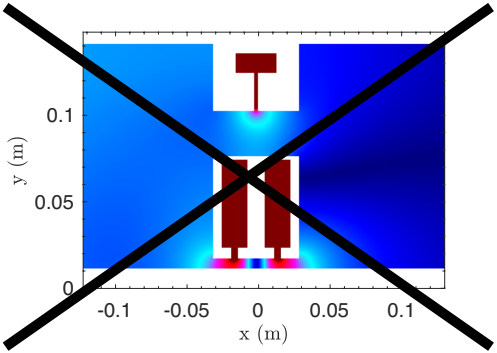



- Numerics is a full wave simulation considering the viscothermal losses.
- Analytics considers to critical effects:
  - Viscothermal losses.
  - Bloch waves, in order to consider the coupling between slits.

If Bloch waves are not considered, i.e., only plane waves are used in the calculations, then the effect is dramatically changed:




- Numerics is a full wave simulation considering the viscothermal losses.
- Analytics considers to critical effects:
  - Viscothermal losses.
  - Bloch waves, in order to consider the coupling between slits.

# Conclusion

- A mirror synmmetric resonator with a degenerate resonance (symmetric and antisymmetric) has been designed as building blocks of an acoustic metascreen presenting perfect absorption independently of the incidence side.
- The resonant scattering produced by the metascreen is analytically studied by a hybrid model mixing the transfer matrix method and the modal decomposition accounting for the Bloch waves in order to consider the possible coupling between the slits.
- The structure is experimentally tested in a square impedance tube showing good agreement with the analytical and numerical predictions.
- The use of other types of resonators as 3D HRs will allow to reach thiner structures with deeper sub-wavelength dimensions.
- The Physics behind this work will motivate the development of broadband and perfect absorption for ventilation problems using cascade processes similar to the case of the rainbow trapping for the unidirectional

# Thank you for your attention

- This work has been funded by the ANR-RGC METARoom (ANR-18-CE08-0021).
- This work has been funded by the HYPERMETA Project funded by Pays Région de la Loire.
- This work is based upon work from COST Action DENORMS - CA15125, supported by COST (European Cooperation in Science and Technology).

# Experimental Evidences of Perfect Acoustic Absorption in Deep Sub-wavelength Structures for the Ventilation Problems.

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e-Forum Acusticum 2020
Dec 7-11, 2020

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