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Zero-Phase Propagation in 1D Realistic Plate-Type Acoustic Metamaterials

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Density-Near-Zero (DNZ) metamaterials

Acoustic metamaterials have drawn considerable attention in the last decades, certainly fuelled by the possibilities of making previously unexpected behaviors real such as the break of the density law^{1,2,3}.

The effective dynamic mass density can take different values from negative, to positive, thus passing through zero density.

When the effective density vanishes, the wavelength tends to infinity leading to a quasistatic field distribution

$$\lambda = \frac{c}{f} = \frac{\sqrt{\kappa}}{\sqrt{\rho}f} \rightarrow \infty. \quad (1)$$

The DNZ metamaterial considered here is a Plate-Type Acoustic Metamaterial (PAM).

Among many other applications for DNZ metamaterials, the non-delayed propagation is detailed in this poster.

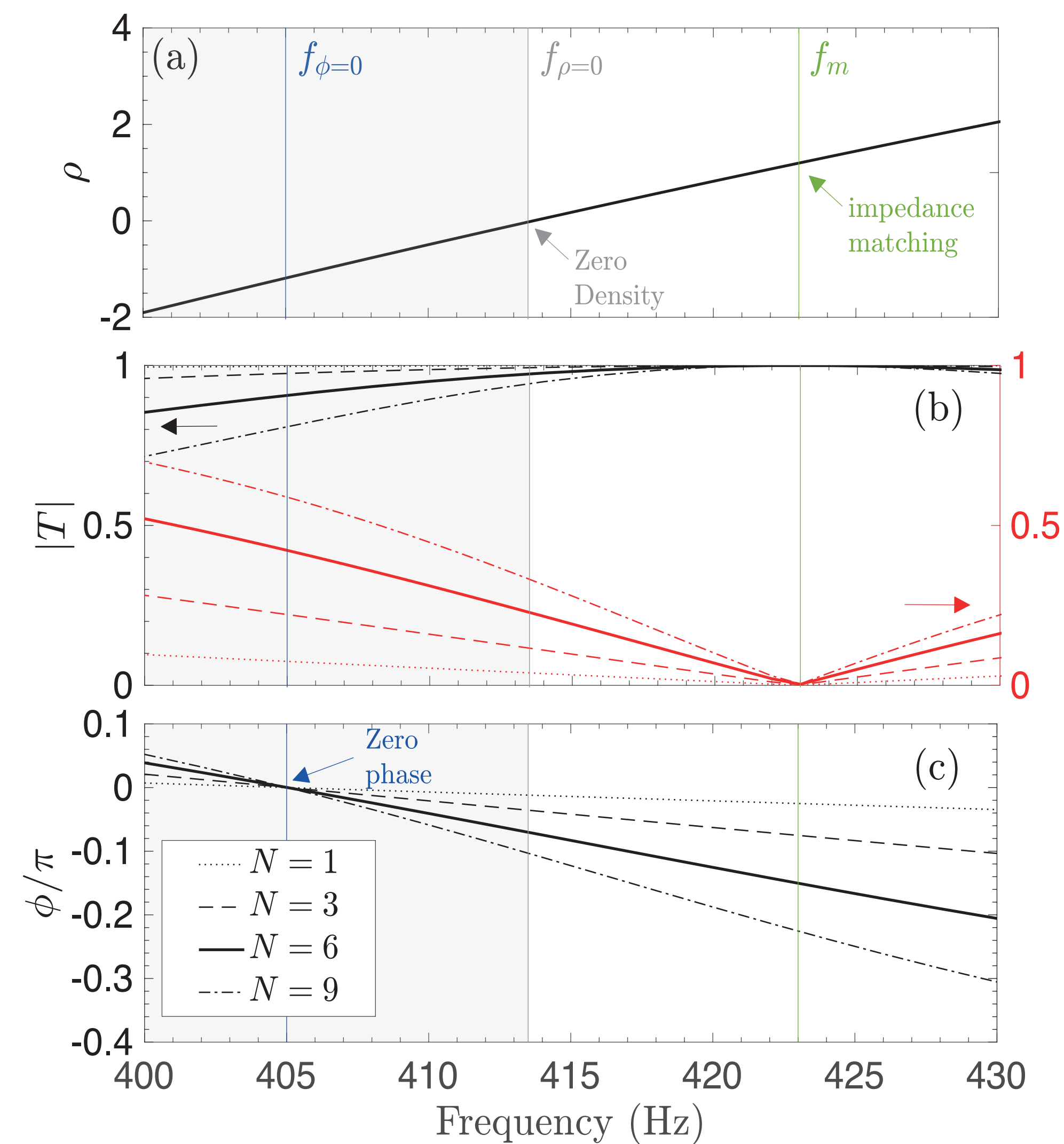
Lossless Plate-Type Acoustic Metamaterials (PAM)

Three characteristic frequencies can be identified:

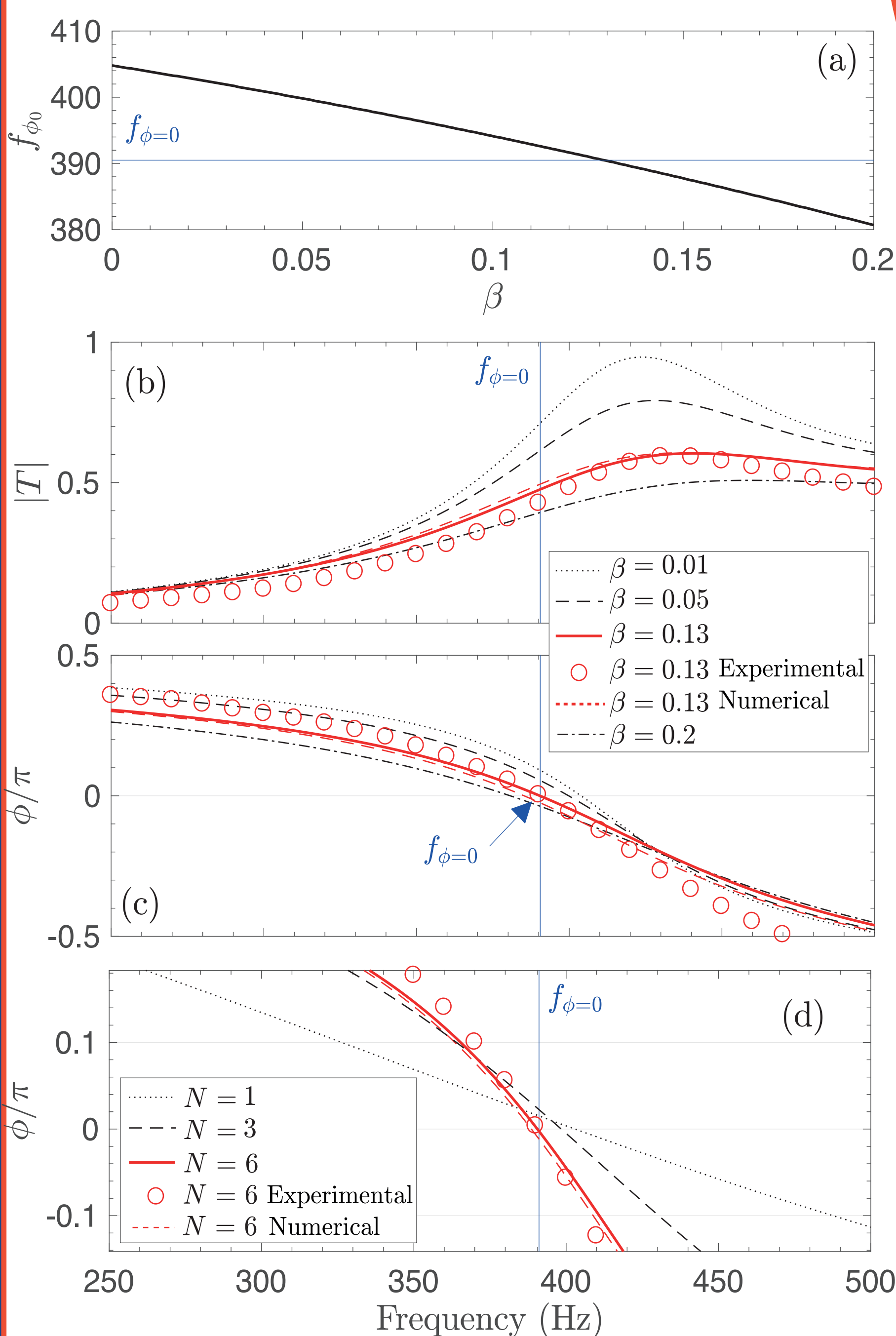
- f_m , the resonance frequency of the plate, where the PAM impedance matches the one of the air, i.e., $|T|=1$, $|R|=0$

- $f_{\rho=0}$, the zero effective density frequency at which impedance mismatch and phase delay occur

- $f_{\phi=0}$, the zero-phase propagation frequency, independent of the number of unit cells, at which impedance mismatch occurs.



Effect of the losses

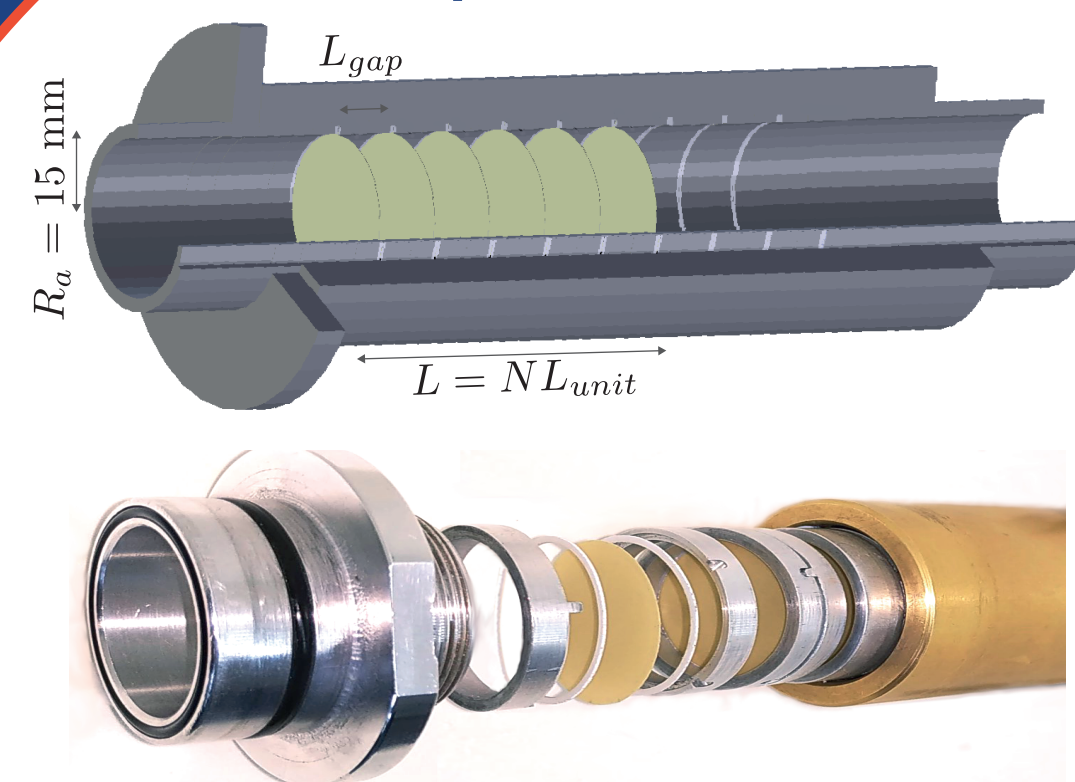


The presence of viscothermal and viscoelastic losses (predominant) induces a small downshift of the zero-phase frequency -less than 10% for the experimental case (red symbols and lines)-.

The measurements show that the zero-phase propagation is robust to losses, and can be observed together with a significant transmission ($|T| \geq 0.4$).

$f_{\phi=0}$ depends on the number of plates. Nonetheless, the phase variation remains lower than 8% for $N \leq 6$ plates.

PAM parameters

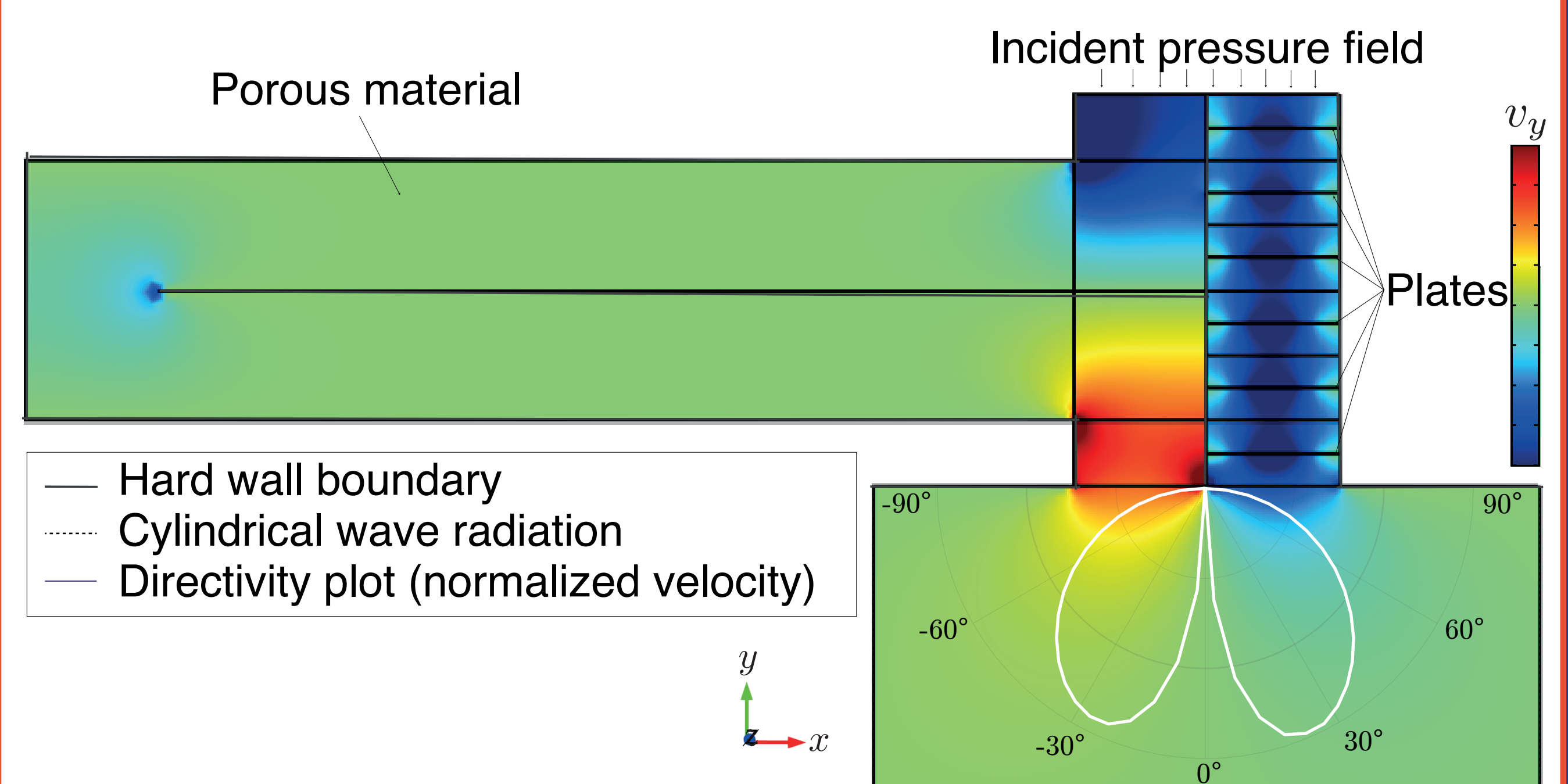


$$E = 4.6(1 + 0.13i) \text{ GPa}, \quad \rho = 1400 \text{ kg.m}^{-3}, \quad \nu = 0.4$$

$$h = 102 \text{ } \mu\text{m}$$

Application of the zero-phase propagation

This peculiar non-delayed propagation property can be efficiently used to design a subwavelength dipole source: one waveguide is filled with a DNZ PAM and the other is a coiled-up Fabry-Perot resonator (FPR) occupied by a porous material.



A dipole source can be approximated by two out-of-phase monopoles, resulting into a two lobes directivity pattern. By designing the length of this FPR such as its first resonance coincides with the zero-phase frequency of the PAM, the acoustic fields at both waveguide ends are out-of-phase.

Conclusions

- Zero-phase propagation has been experimentally, numerically and analytically reported. The corresponding working frequency lies into the negative effective density regime, i.e., in the PAM stop band, is lossy dependent, and leads to impedance mismatch;
- The amplitude of the transmission at $f_{\phi=0}$ depends on the number of unit cells in the systems;
- Considering $N \leq 6$ allows to have both sufficiently high transmission to be measurable and a phase variation at $f_{\phi=0}$ lower than 8%;
- Finally, an acoustic dipole source has been designed using the non-delayed propagation property of the PAM.

References

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