Extraordinary Acoustic Transmission mediated by Helmholtz Resonators

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Abstract

We demonstrate perfect transmission of sound through a rigid barrier embedded with Helmholtz resonators (HR). The resonators are oriented such that one neck protrudes onto each side of the barrier. Perfect sound transmission occurs even though the open area of the necks is less than 3% of the barrier area. Maximum transmission occurs at the resonant frequency of the Helmholtz resonator. Because the dimensions of the Helmholtz resonators are much smaller than the resonant wavelength, the transmission is independent of the direction of sound on the barrier and of the relative placement of the necks. Further, we show that the transmitted sound experiences a continuous phase transition of π radians as a function of frequency through resonance. In simulations of adjacent resonators with slightly offset resonance frequencies, this phase difference leads to destructive interference in the far field. By manipulating the phase of a plane acoustic wave, Helmholtz resonator arrays can create a new class of acoustic beam-forming devices analogous to diffractive optics.

Simulation Configuration

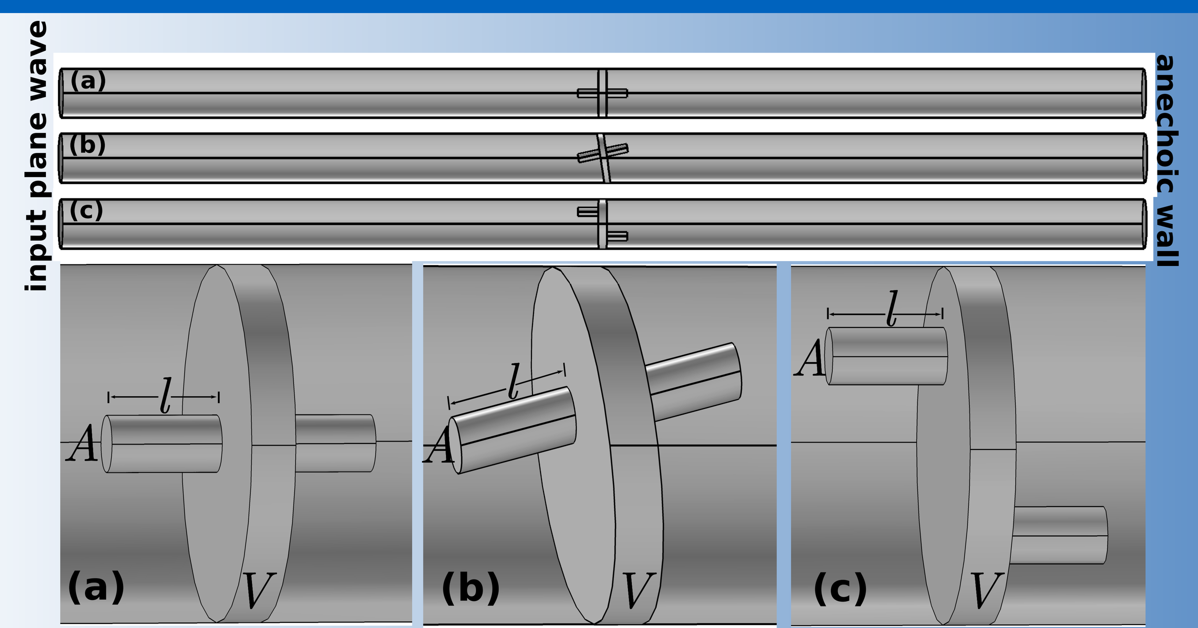


Fig. 1: Schematic of the configuration being simulated. Full view showing the input and output ends of the waveguide. Also, a close-up of the Helmholtz resonator labeled to indicated neck length, opening area, and eclosed volume. The central element in the system described here is a two-neck variation of the HR comprised of necks of length, l, and cross-sectional opening of area, A, that leads to an enclosed chamber of volume, V. Simple harmonic oscillation results because the air in the neck acts as a mass and the trapped volume of air in the chamber acts as an effective spring. The resonant frequency of the two-neck simple harmonic oscillator is determined by its physical dimensions and is given by

$$f_r = \frac{v}{2\pi}\sqrt{\frac{2A}{L'V}}\,,$$

where v is the speed of sound in air and $L' = l + 1.5a$ is the effectiveneck length. a is the radius of the neck opening.

Extraordinary Acoustic Transmission

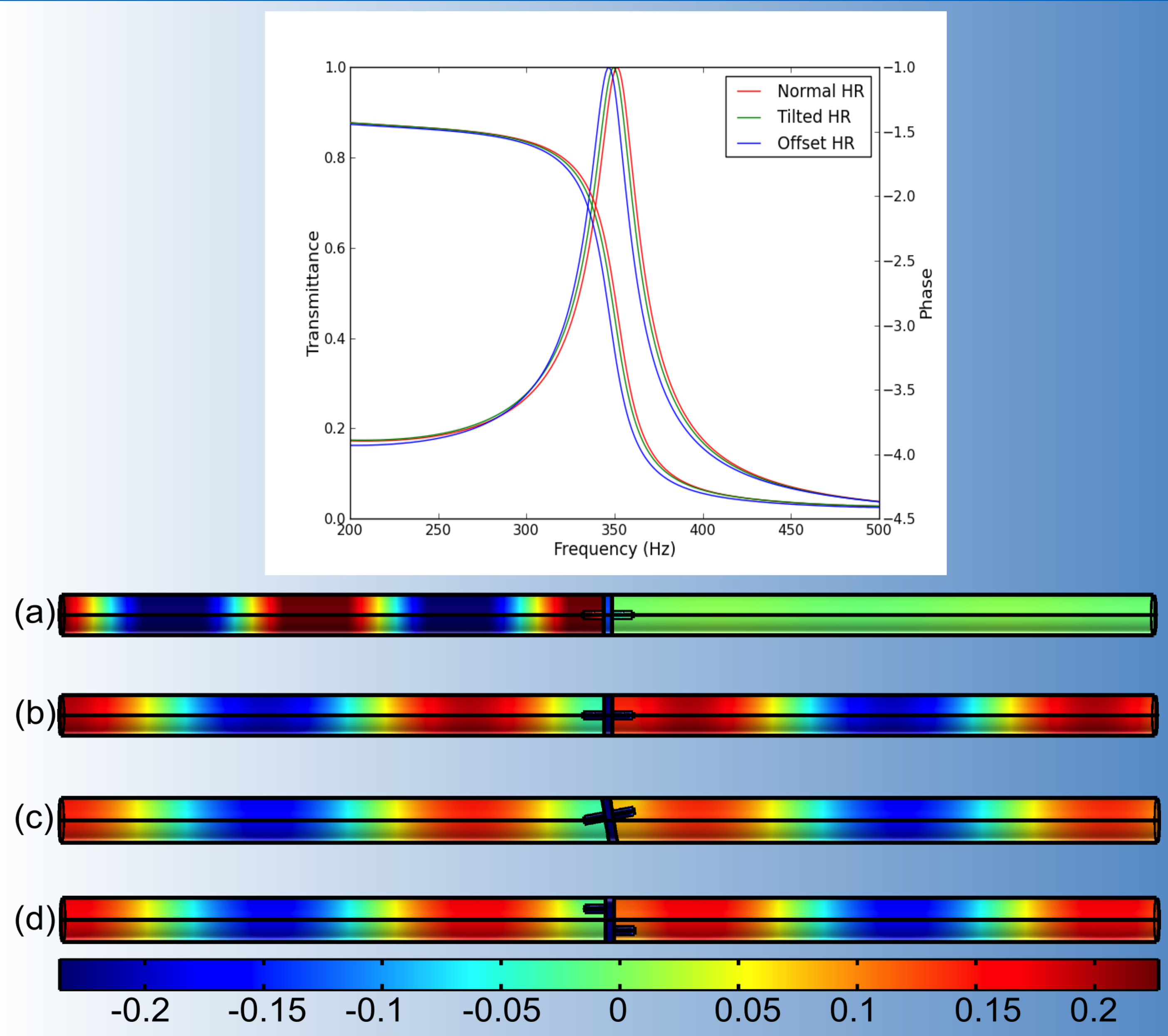


Fig. 2: (Up) Plot of transmission amplitude and phase versus frequency. Tramission amplitude is referenced to the left hand vertical axis and the phase to the right hand vertical axis. (Down) (a) Pressure amplitude plot at 500 Hz. In this off-resonance case there is no transmitted amplitude (see the color map scale at the bottom of the figure). Pressure amplitude plots for the (b) straight, (c) tilted, and (d) offset HR embedded barriers, all showing almost extraordinary and identical acoustic transmission at their resonant frequency (~350Hz).

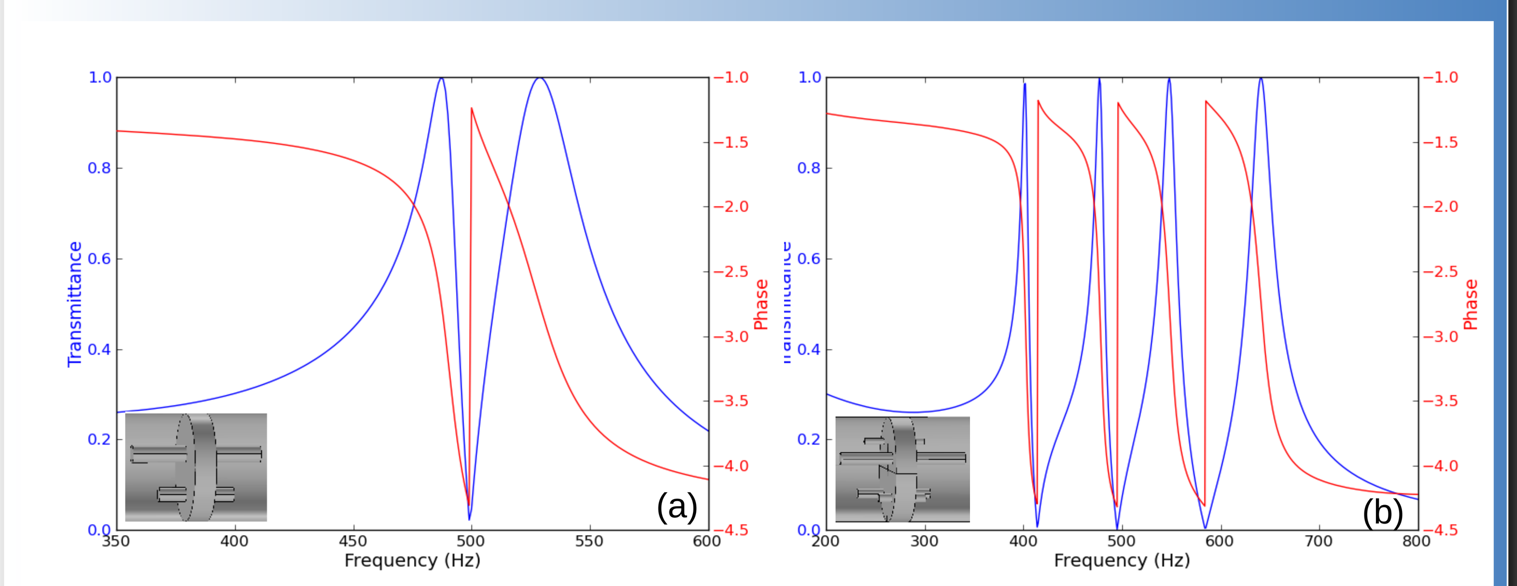


Fig. 3: (a) Transmission amplitude (left hand axis) and phase (right hand axis) versus frequency of two adjacent resonators with different resonant frequencies showing interference due to the phase shift above and below resonance. (b) Transmission amplitude (left hand axis) and phase (right hand axis) versus frequency of four resonators with sequentially offset resonant frequencies. This particular ability to modulate phase shifts using different configurations of HRs can be used to designed acoustic lenses which can focus acoustics waves.

Verification of the Numerical results

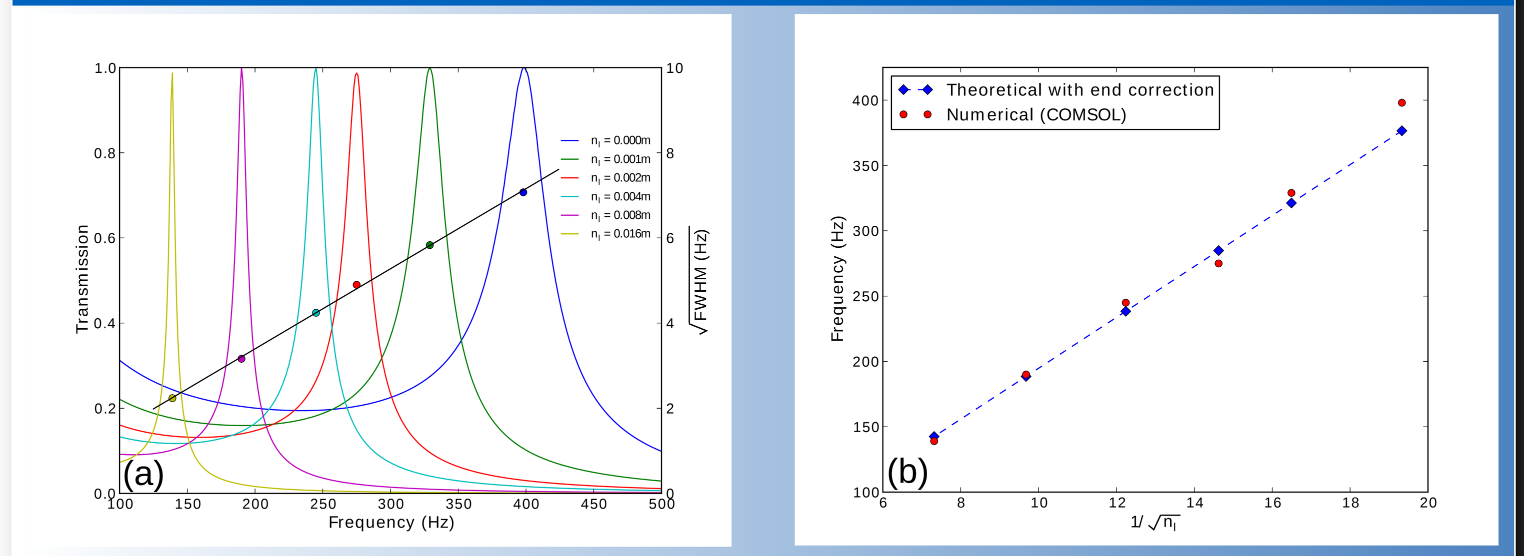
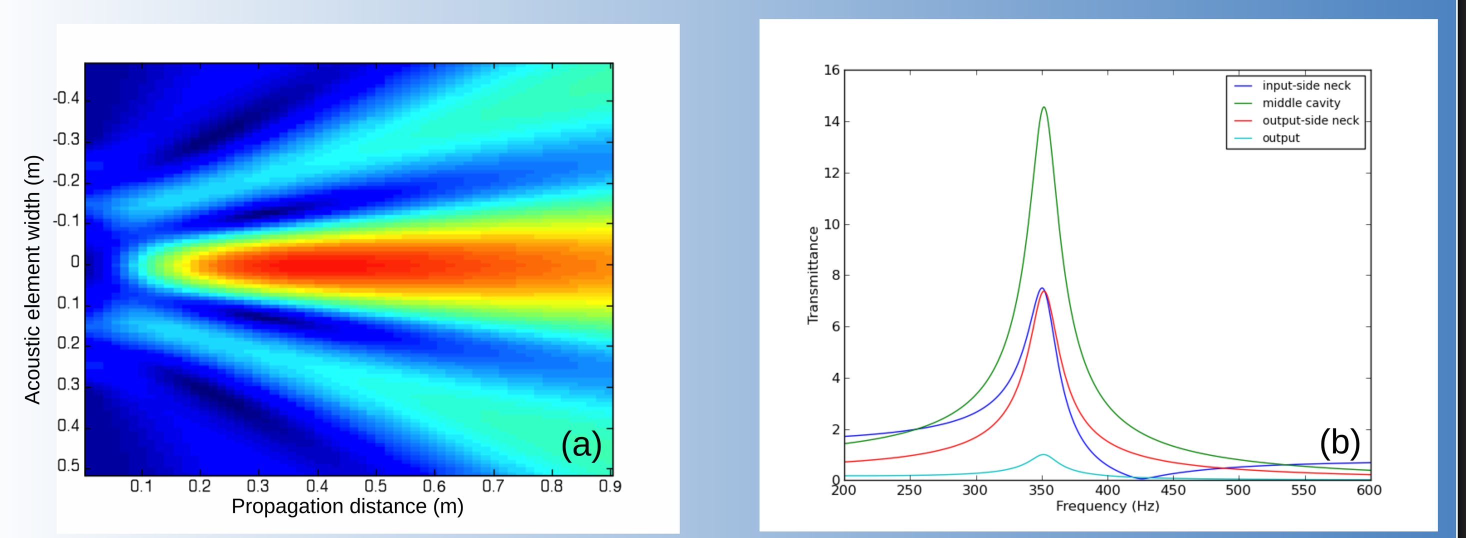


Fig. 4: (a) Plot of transmission amplitude (left hand axis) and square-root of Full Width Half Maximum (FWHM) measure of transmission bandwidth at different neck lengths, showing that the neck length and transmission bandwidth are inversely proportional. (b) Resonant frequency versus $1/\sqrt{n_l}$. The blue dots are the theoretical predictions, and the red dots are the numerical results, which show very good agreement.

Future Directions



- Design acoustic element that can focus acoustic waves. An example of acoustic focusing is shown in Fig. 5 (a).
- Conduct an actual experiment to show extraordinary acoustic transmission using 2 necked Helmholtz resonators as show in Fig. 1.
- Study the possibility of using embedded 2 necked Helmholtz resonators for gas sensing. The transmission amplitude at the necks and the cavity are enhanced significantly (Fig. 5 (b)), which can be used for making gas sensors.

References

- H. J. Pain, Physics of Vibration and Waves (Wiley, Chichester, 2008).
- J. W. Herlan, S. S. LePard, and W. M. Robertson, J. Appl. Phys. 113, 124903 (2013).
- J. J. Park, K. J. B. Lee, O. B. Wright, M. K. Jung, and Sam H. Lee, Phys. Rev. Lett. 110, 244302 (2013).
- Y. Zhou, M. H. Lu, L. Feng, X. Ni. Y, F. Chen, Y. Y. Zhu, S. N. Zhu, and N. B. Ming, Phys, Rev. Lett. 104, 164301 (2010).