# Noise Reduction Using Structures Based On Coupled Helmholtz Resonators

Mariia Krasikova[1], Yuri Baloshin[1], Alexey Slobozhanyuk[1], Anton Melnikov[2], David Powell[3], Mikhail Petrov[1] and Andrey Bogdanov[1]

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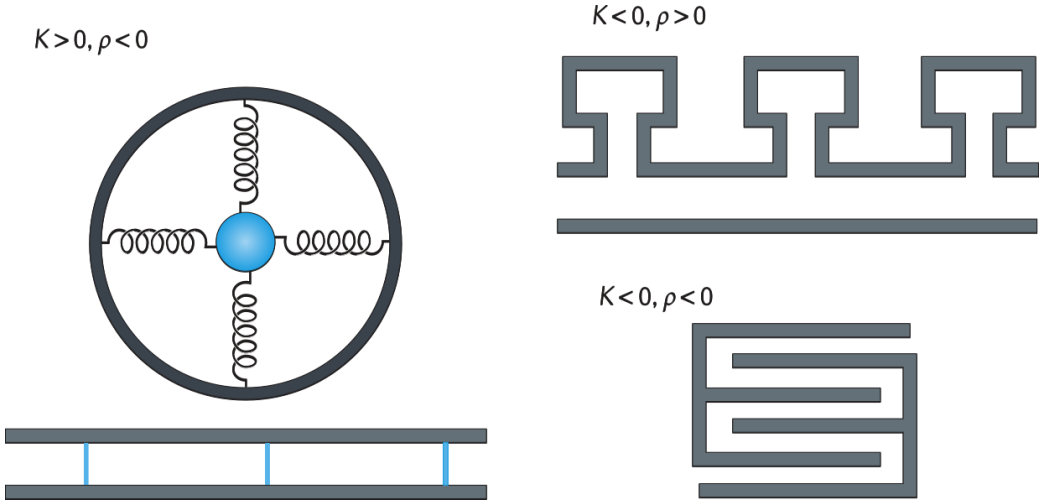
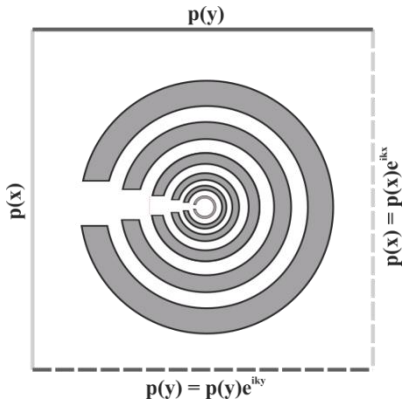
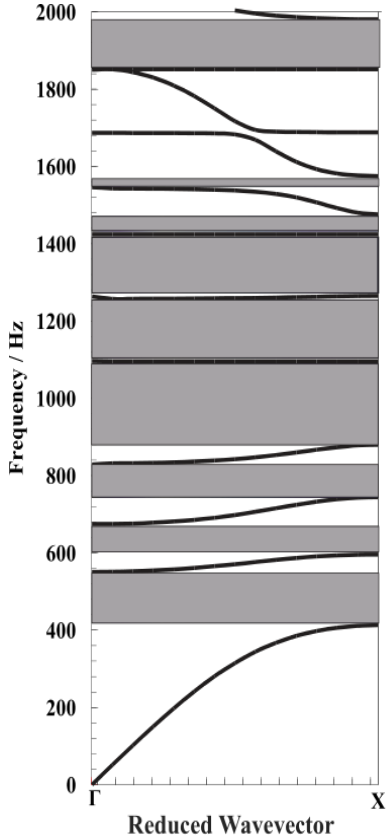
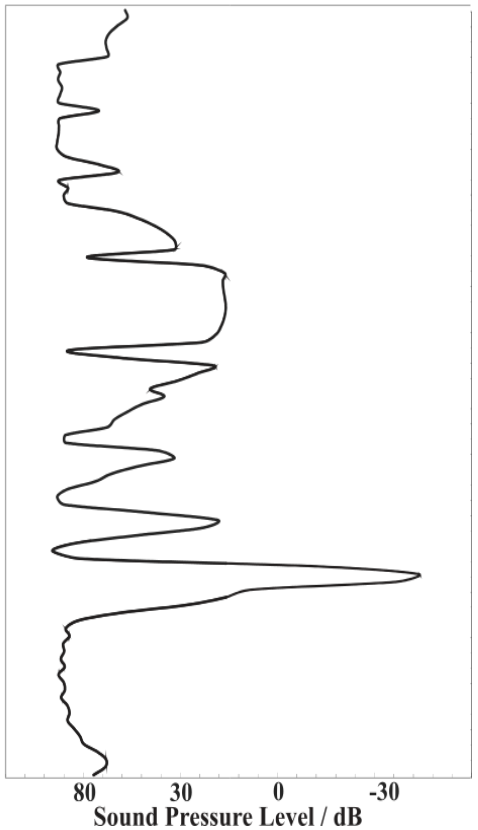
Acoustic metamaterials [1] are artificial subwavelength structures with negative mass density $\rho$ and bulk modulus $K$, which are positive in natural materials.




The presence of wide band gaps in such structures suggests that they may be used for the realization of broadband noise insulators [2].




[1] Cummer S. A., et al. (2016). *Nature Reviews Materials*, **1**(3), 1–13
[2] D. P. Elford, et al. (2011) *The Journal of the Acoustical Society of America*, **130**, 2746–2755

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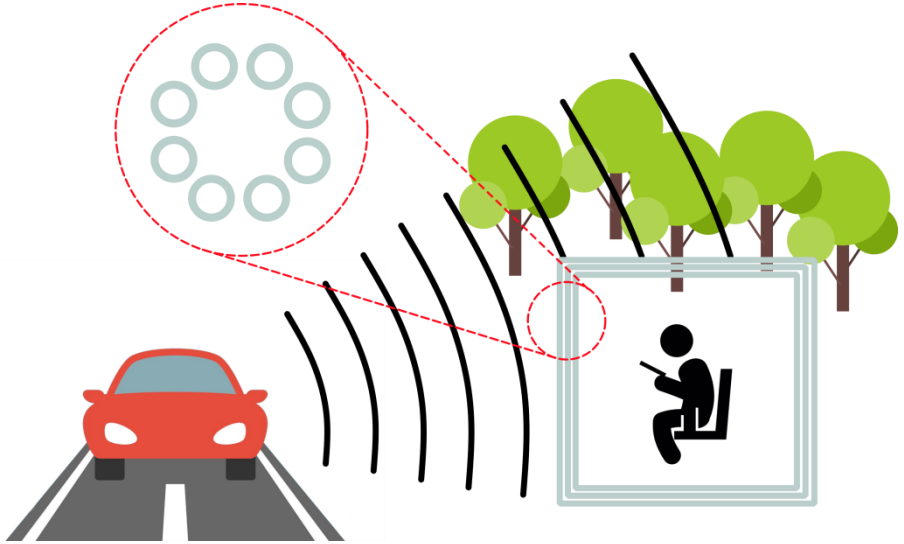
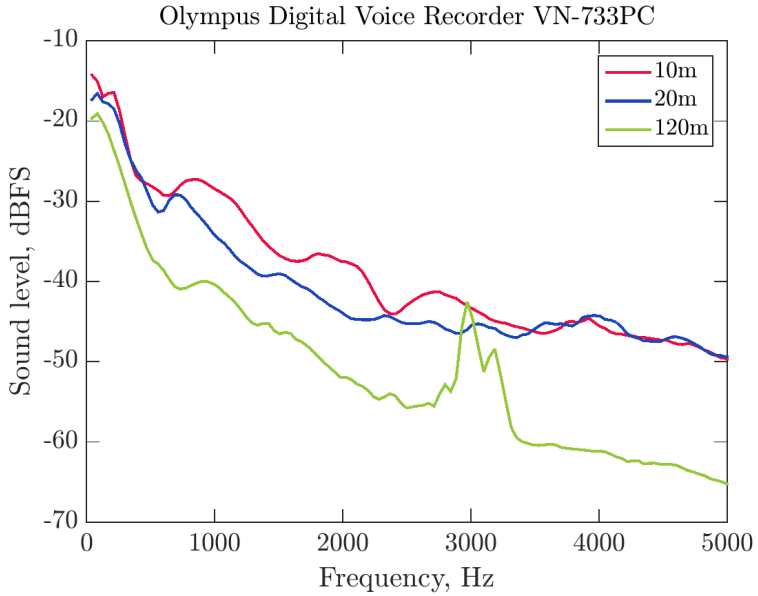
Aim of this work is to develop a noise insulating structure made of rigid and lightweight elements available commercially. In particular, C-shaped coupled Helmholtz resonators [3,4] made of polymer water pipes are analyzed.

One of the main goals is to reduce noise in the audible range of sound to insulate street noises.






Noise level measured in a park at different distances from a road.

[3] A. Melnikov, et al. (2019) *Nature Communications*, **10**, 1–7 (2019)
[4] A.Melnikov, et al. (2020) *The Journal of the Acoustical Society of America*, **147**, 1491–1503

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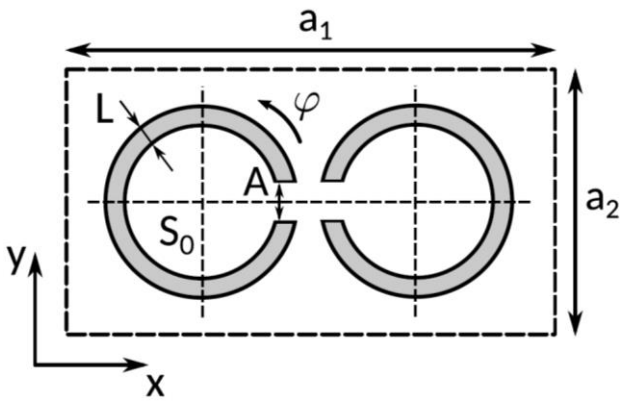
ITMO UNIVERSITY

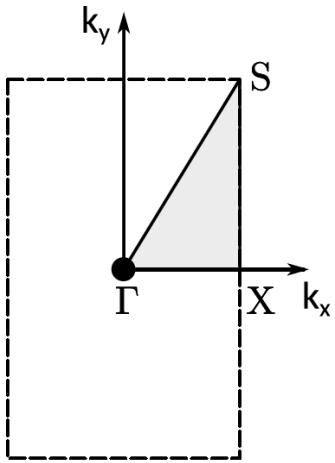
department of PHYSICS



## Geometry

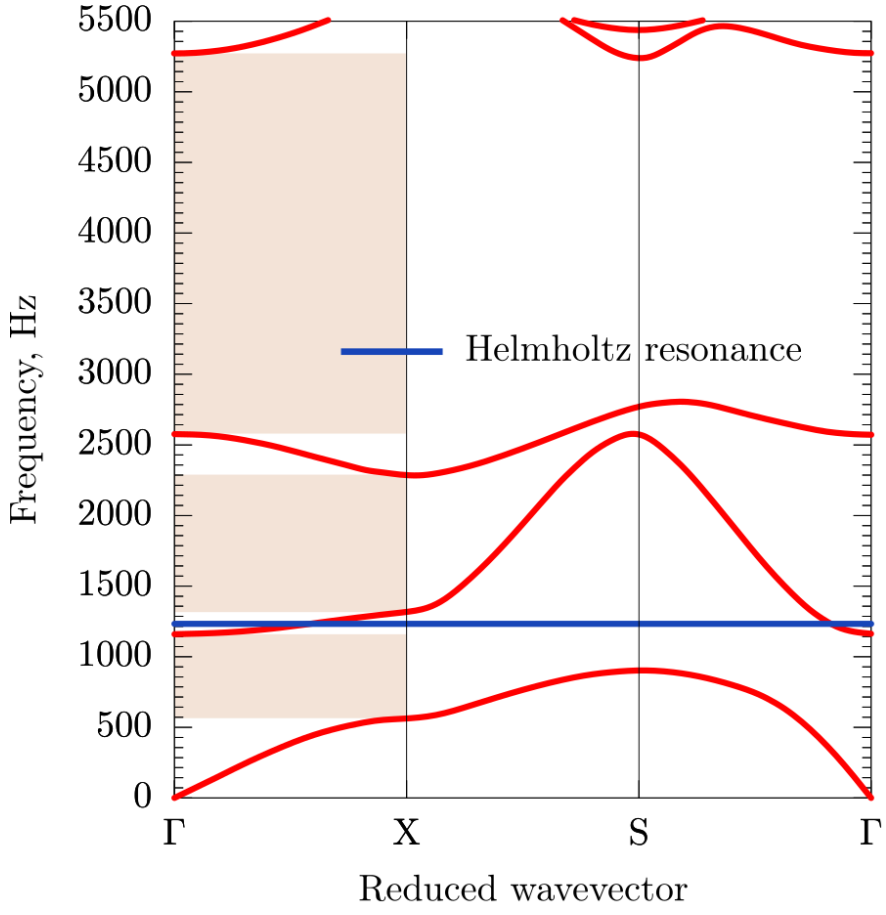
First of all, we considered the infinite 2D structure with the following Brillouin zone:




Presented band diagram was calculated for following parameters: L = 1.9 mm, A = 4 mm, $a_1$ = 85 mm, $a_2$ = 45 mm, $\varphi$ = 0°.
Outer radius of pipes was equal to 20 mm. Distance between centers of rings is 45 mm.
Pipes are made of polypropylene with Young's modulus 1.35 GPa, Poisson's ratio 0.41 and density 900 kg/m$^3$.

## Band diagram




This design allows achieving band gaps within *ΓX* interval with a **total width of about three octaves.**

Blue horizontal line at 1231 Hz corresponds to the *Helmholtz resonance*, which is an anti-symmetric mode.

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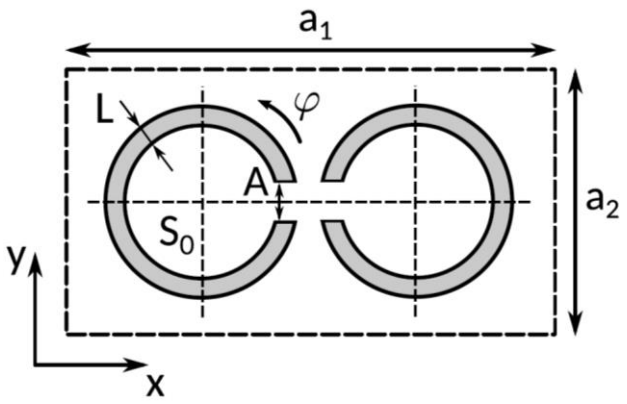


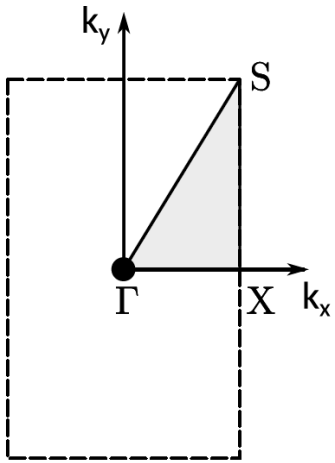


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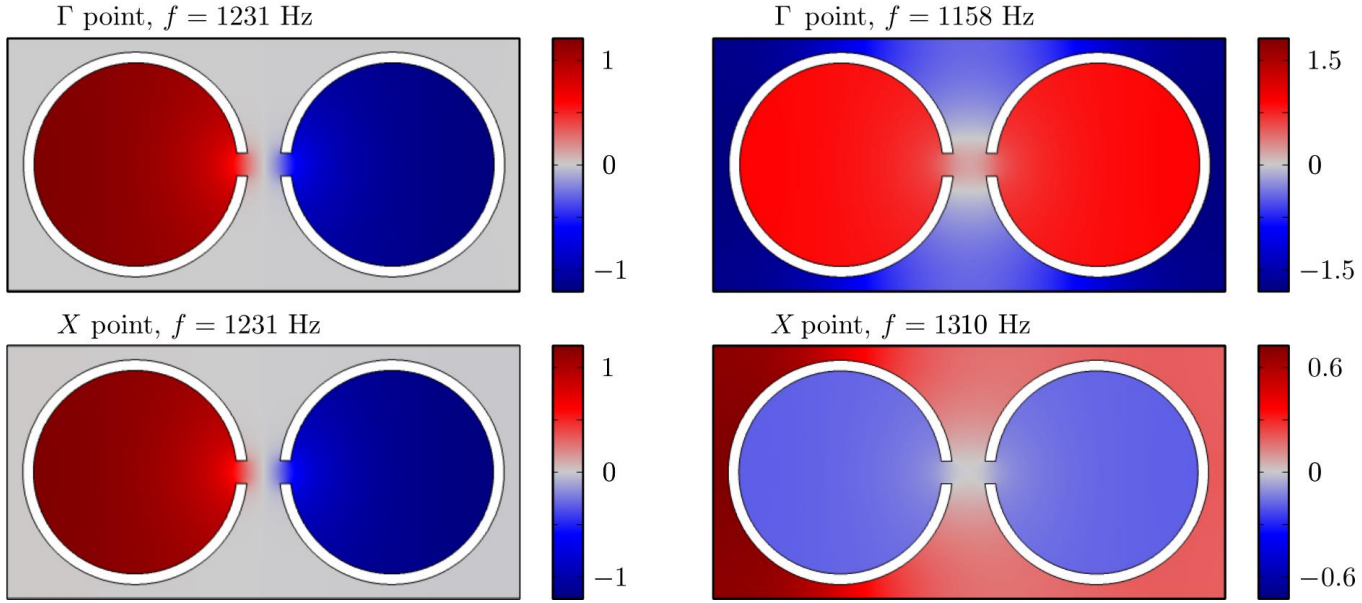
## Helmholtz resonance

**Estimated frequency of Helmholtz resonance [5] is $f_{res}$ ≈ 1215 Hz**:

$$f_{res} = \frac{c}{2\pi}\sqrt{\frac{A}{S_0 L_{eff}}}$$

$L_{eff}$ is the effective length of the neck, $L_{eff} = L + 1.05A$,
$S_0$ – static area of the cavity, $S_0 = \pi (R_{out} - L)^2$,
$c$ – speed of sound in resonator's environment (air, 343 m/s)
A – width of slit in a pipe




[5] L. E. Kinsler, et al., *Fundamentals of Acoustics, 4th Edition* (1999).

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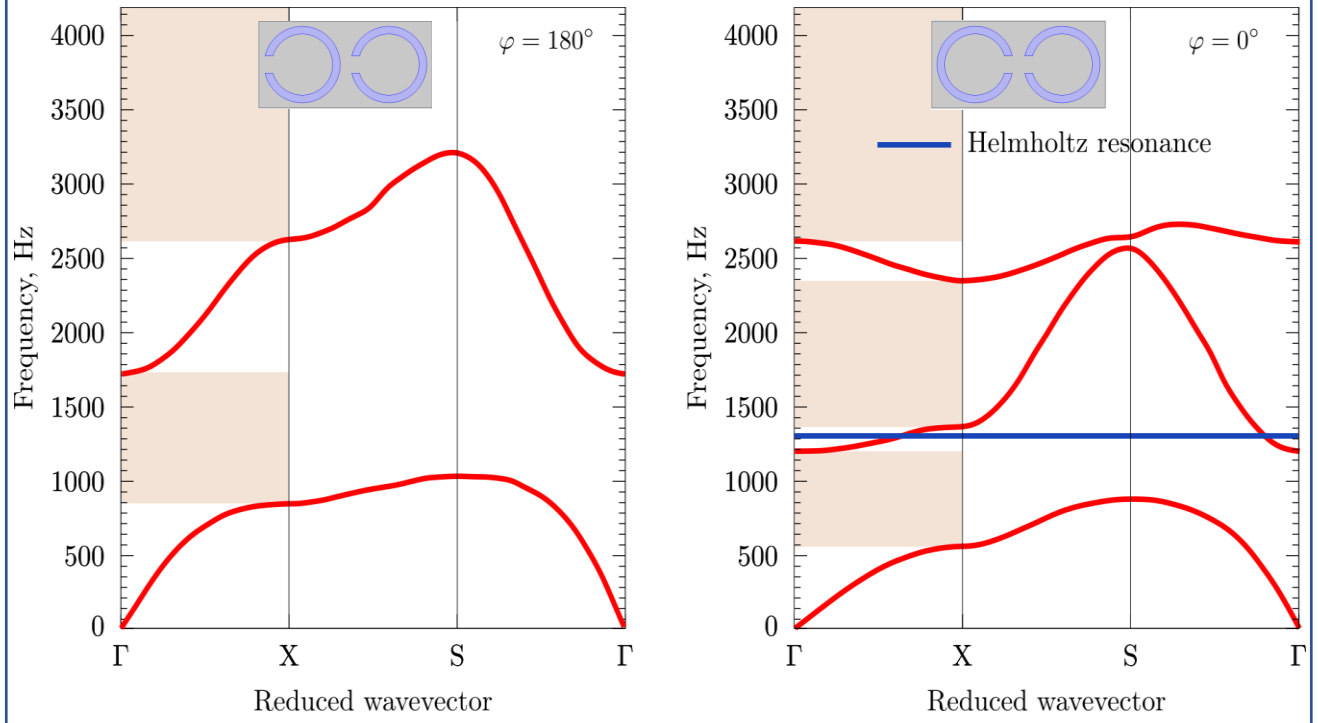
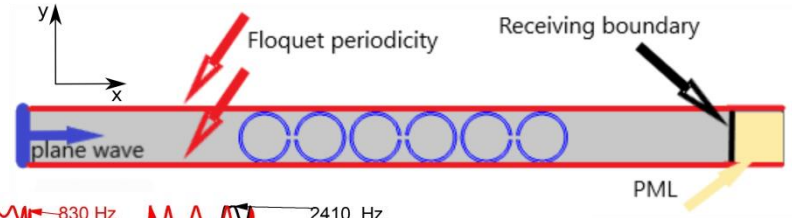
## Band diagrams for infinite structures with different coupling

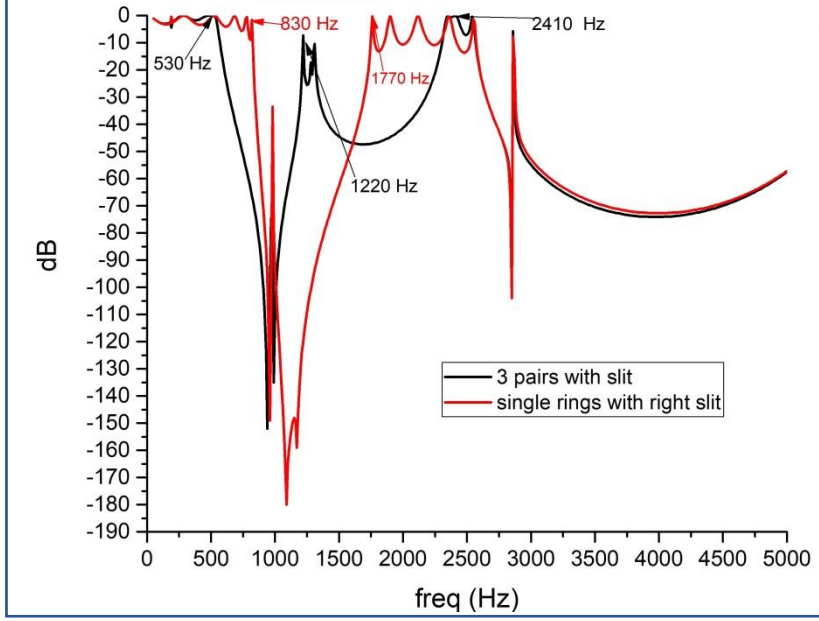
If resonators are faced to each other (phi = 0), total width of band gaps is larger due to additional coupling.




## Transmission spectrum of semi-infinite structures

Structure is infinite along *y* axis and finite along *x* axis (3 pairs of coupled rings or 6 single rings with slit).




For strongly coupled rings first band gap is two times larger.

All band gaps in this case coincide with band gaps for infinite structures.

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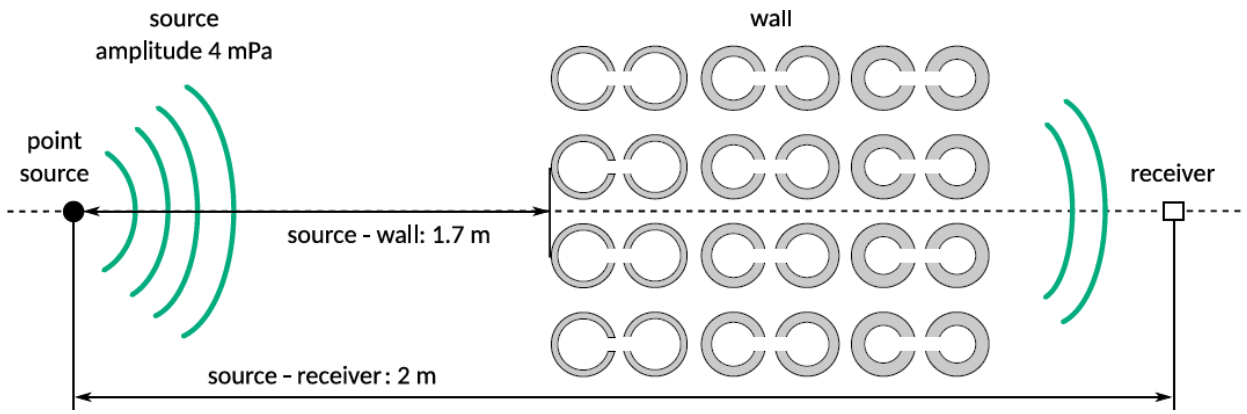
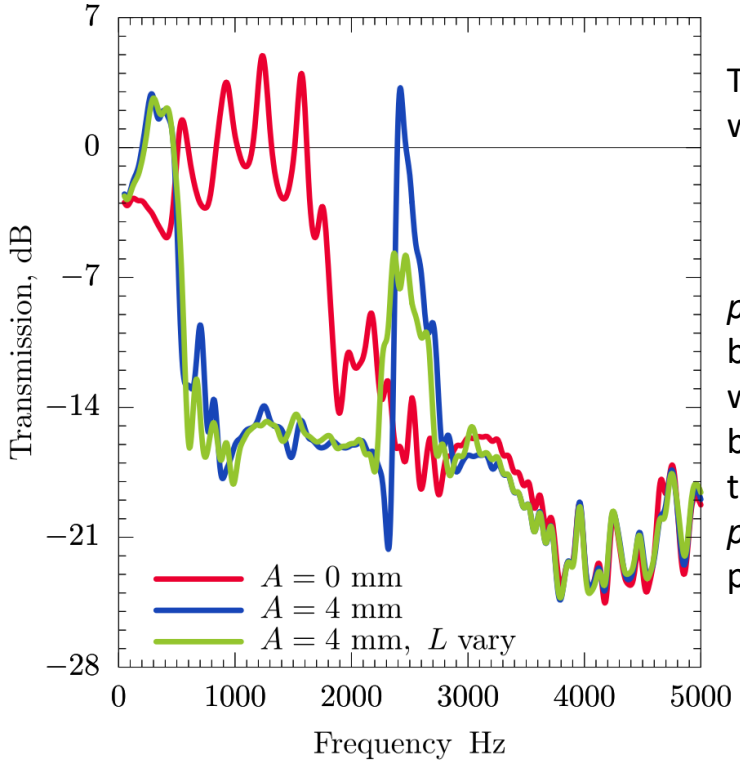
## The scheme of the numerical experiment




Point source is placed 1.7 m apart the wall consisting of three layers of element's pairs. Each layer is characterized by different values of $L_0$, but all other parameters are the same. Then the signal, transmitted through the wall, is analyzed at the receiver location. Distance between the port and the source is 2 m.

Several cases were considered: the pipes without slits, coupled Helmholtz resonators of same $S_0$ and three pairs of coupled resonators $L_{01}$ = 1.9 mm, $L_{02}$ = 3.8 mm, $L_{03}$ = 5.7 mm (all other parameters are the same).

## Comparison of the transmission at the receiver location




Transmission coefficient was calculated as

$$T = 20 \cdot \log\left( p_{wall} / p_{air} \right)$$

$p_{wall}$ – the pressure created by the source in the case when there is no wall between the source and the receiver

$p_{air}$ – the pressure in the presence of the wall

Dips in transmission in this case correspond to band gaps of infinite structures.

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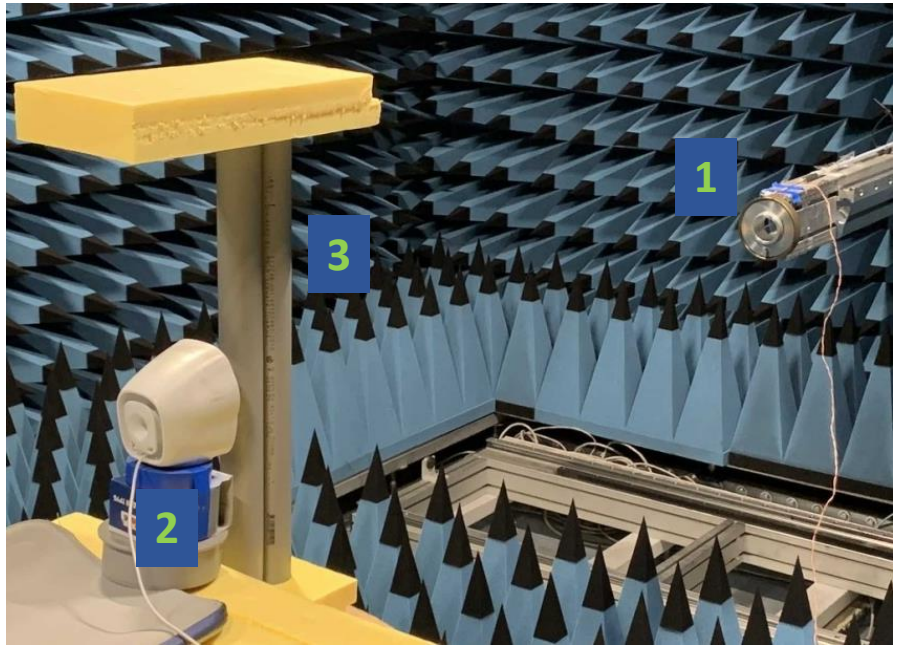
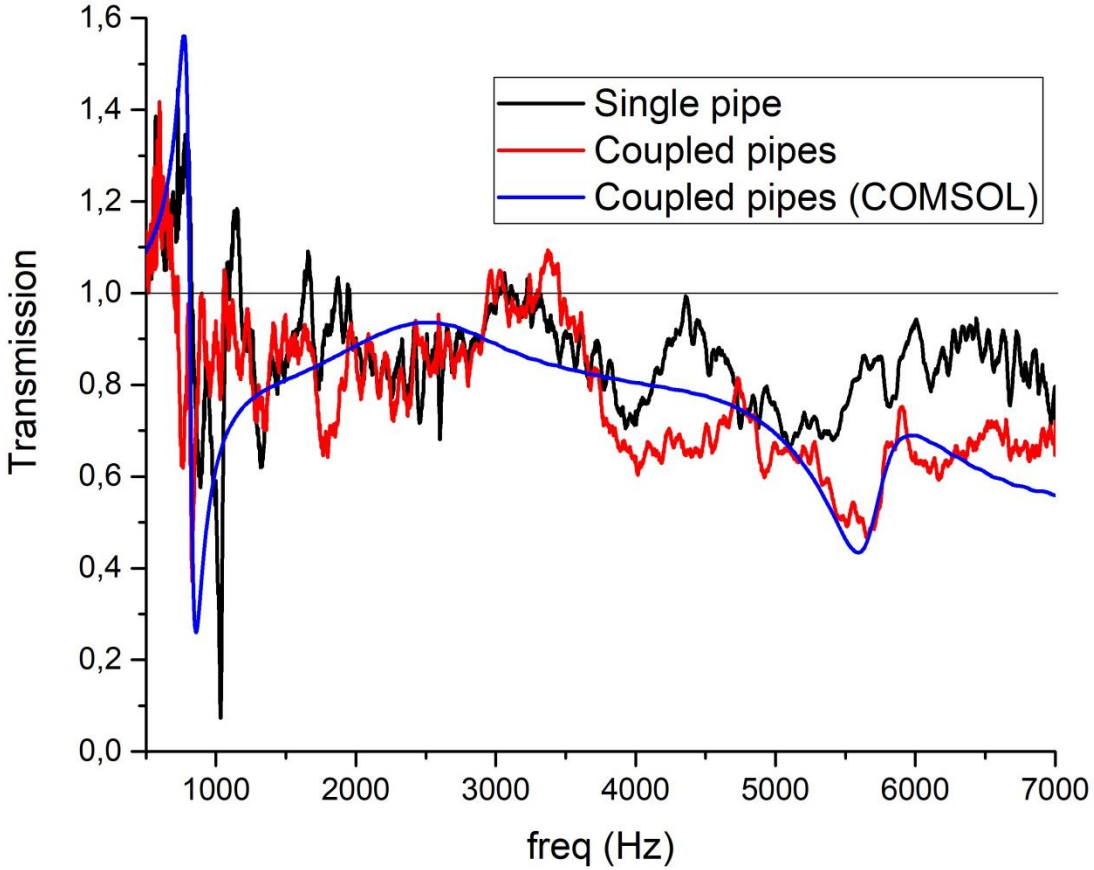
## Comparison of the experiment and simulation

Photography of the experimental setup




1 – microphone
2 – loudspeaker
3 – pipes (outer radius 20 mm, thickness 2 mm, distance between pipes 5 mm, slit 4 mm, height of pipes 50 cm)

Transmission of the signal from loudspeaker throw single pipe and 1 pair of coupled resonators



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1. We have demonstrated that broadband noise insulation can be achieved with several layers of coupled C-shaped resonators, which can be made of polymer water pipes.

2. These results may become useful for the realization of simple and lightweight insulating structures.

3. The ongoing research aims to validate obtained results with experimental demonstrations.

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