Acoustic barriers based on locally resonant sonic crystals

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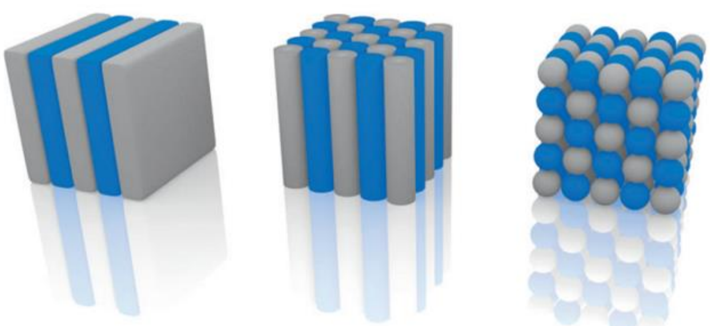

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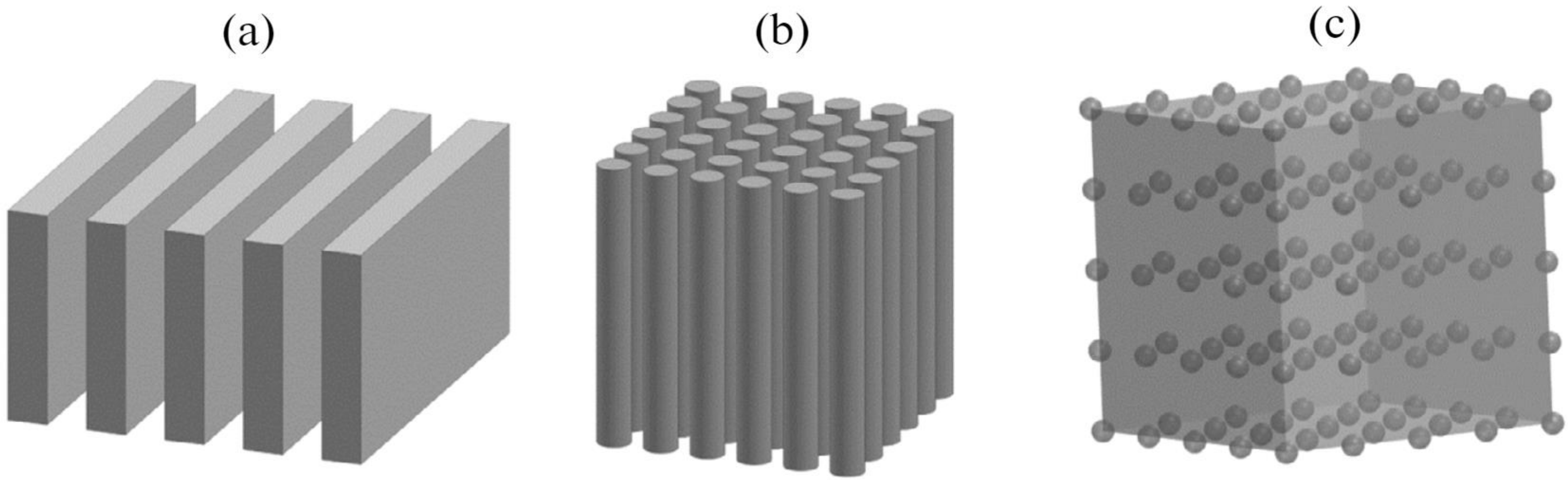
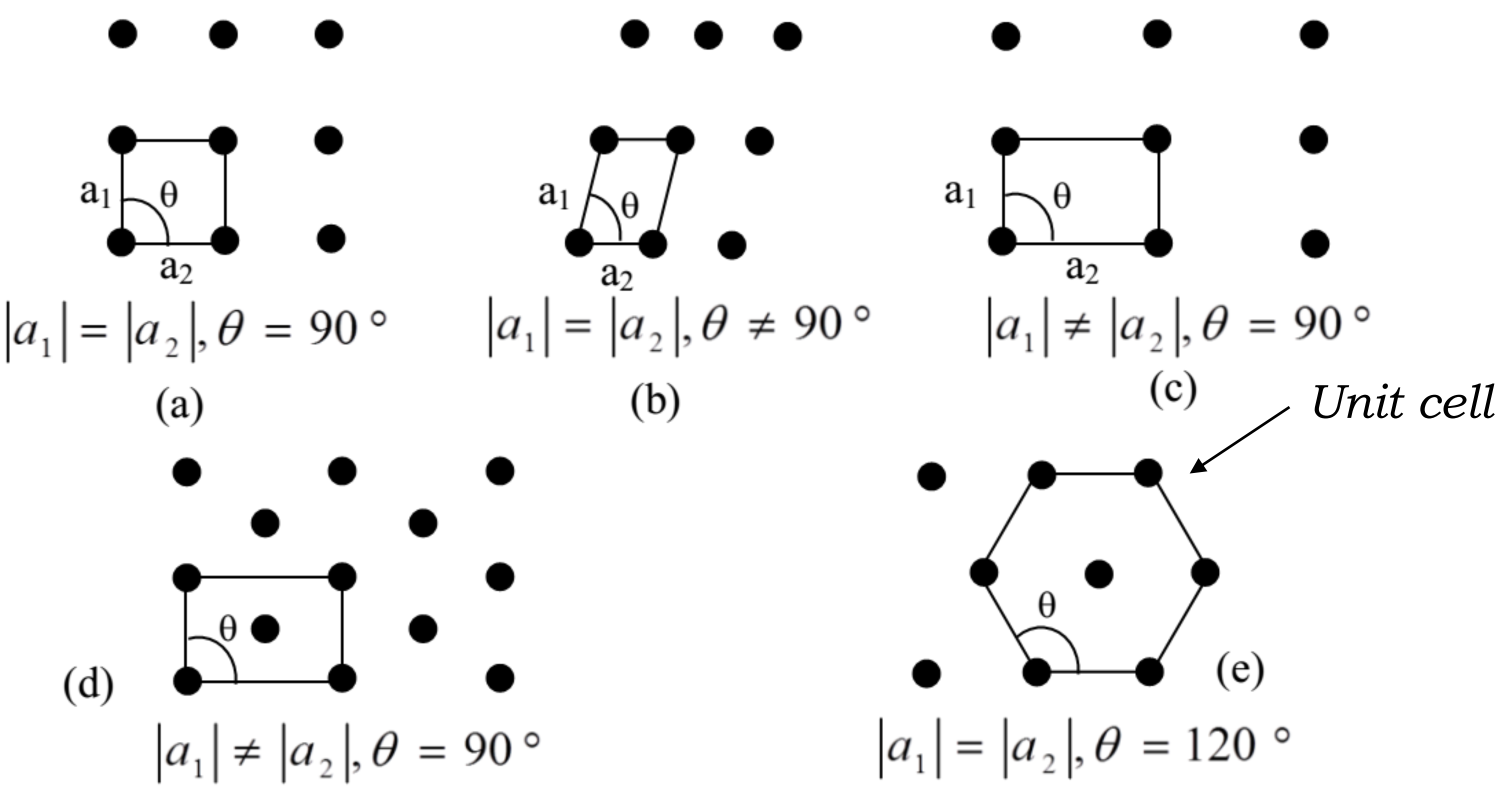
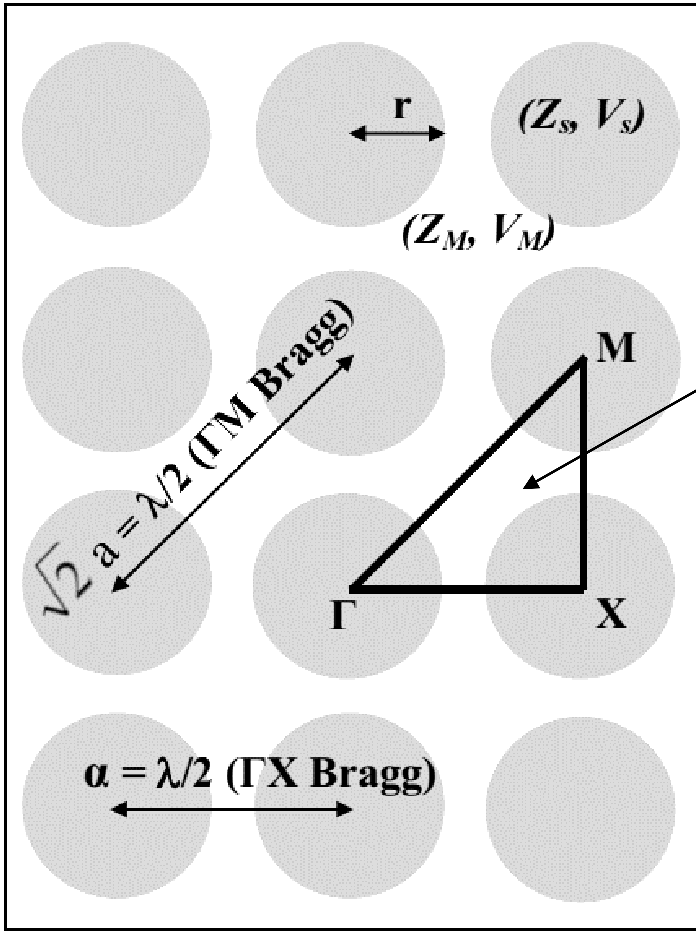
- **Sonic crystals** are artificial structures made by the periodic arrangement of scatterers
- The scatterers are soundhard (i.e., having a high acoustic impedance) with respect to the medium in which they are placed
- Due to the periodic arrangement of scatterers,sonic crystals have a unique property of selective sound attenuation in specific range of frequencies (band gap)



(a) 1D sonic crystal consisting of plates arranged periodically;
(b) 2D sonic crystal with cylinders arranged on a square lattice;
(c)3D sonic crystal consisting of periodic arrangement of sphere in simple cubic arrangement.

A **lattice** is a regular, periodic array of points in space.
In two dimensions, it is defined by two vectors: $a1$, $a2$





A two dimensional periodic structure made of circular scatterers arranged on a square lattice

Z_s – acoustic impedance (scatterer)

V_s – prędkość dźwięku (scatterer)

Z_m – acoustic impedance (medium)

V_m – speed of sound (medium)

ΓM, ΓX – direction of the sound wave propagation

Brillouin zone

r – radius of the scatterer

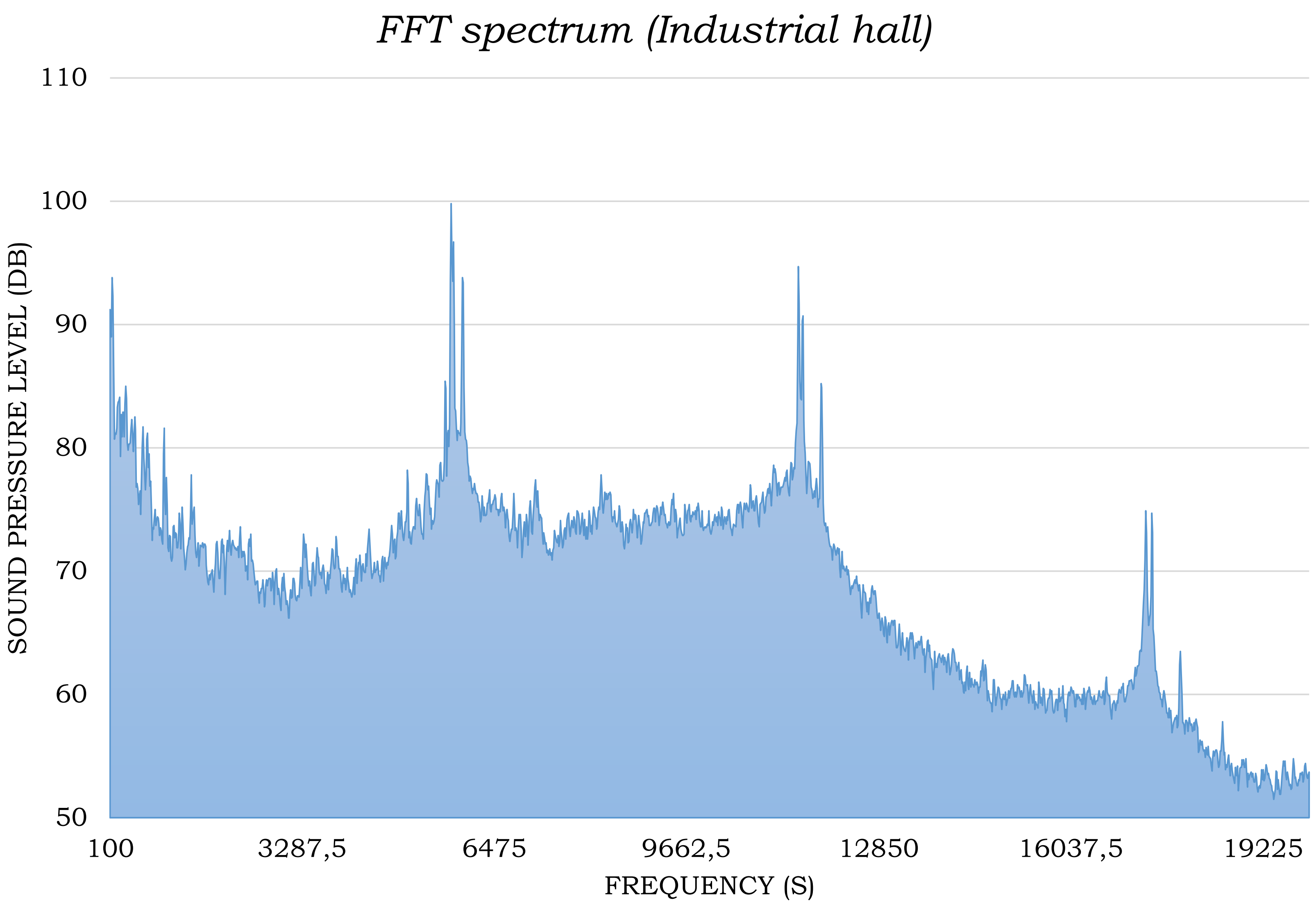
λ – wavelength

Bragg'slaw given by

$$f_{Bragg_{\Gamma X}} = \frac{V_m}{2L}$$

$$f_{Bragg_{\Gamma M}} = \frac{V_m}{\sqrt{2}(2L)}$$

First experimental revelation of the sonic crystal was found by an artistic structure designed by ***Eusebio Sempere*** *in Madrid.*

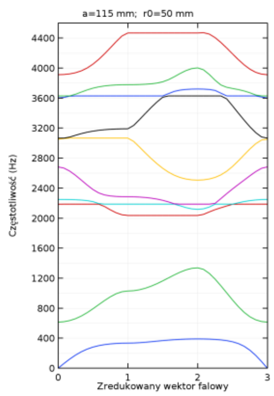

FFT spectrum (Industrial hall)
110
100
90
80
70
60
50
SOUND PRESSURE LEVEL (DB)
100
3287,5
6475
9662,5
12850
16037,5
19225
FREQUENCY (S)

Techniques to calculate the band structures

Plane Wave Expansion Method (PWE)

The main technique of PWE is to expand the system parameter functions (density, speeds) and wavefunctions by plane waves in the wave equation in Fourier series.

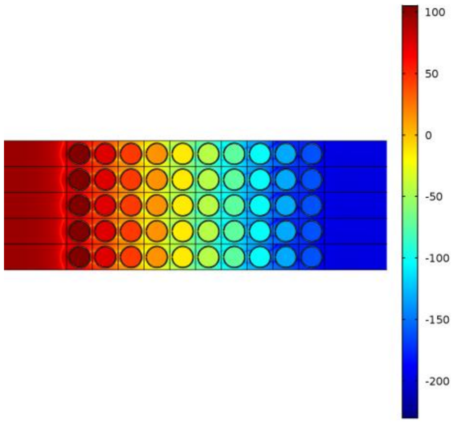
An infinite periodic array of scatterers can be modelled by applying the Floquet-Bloch theorem to the PWE. The PWE method can be applied to a phononic crystal with any shape of scatterer but only infinite arrays can be modelled.



The Finite Element Method (FEM)

The underlying premise of the FEM is that a complicated domain can be divided into a series of small regions in which the differential equations are approximately solved.

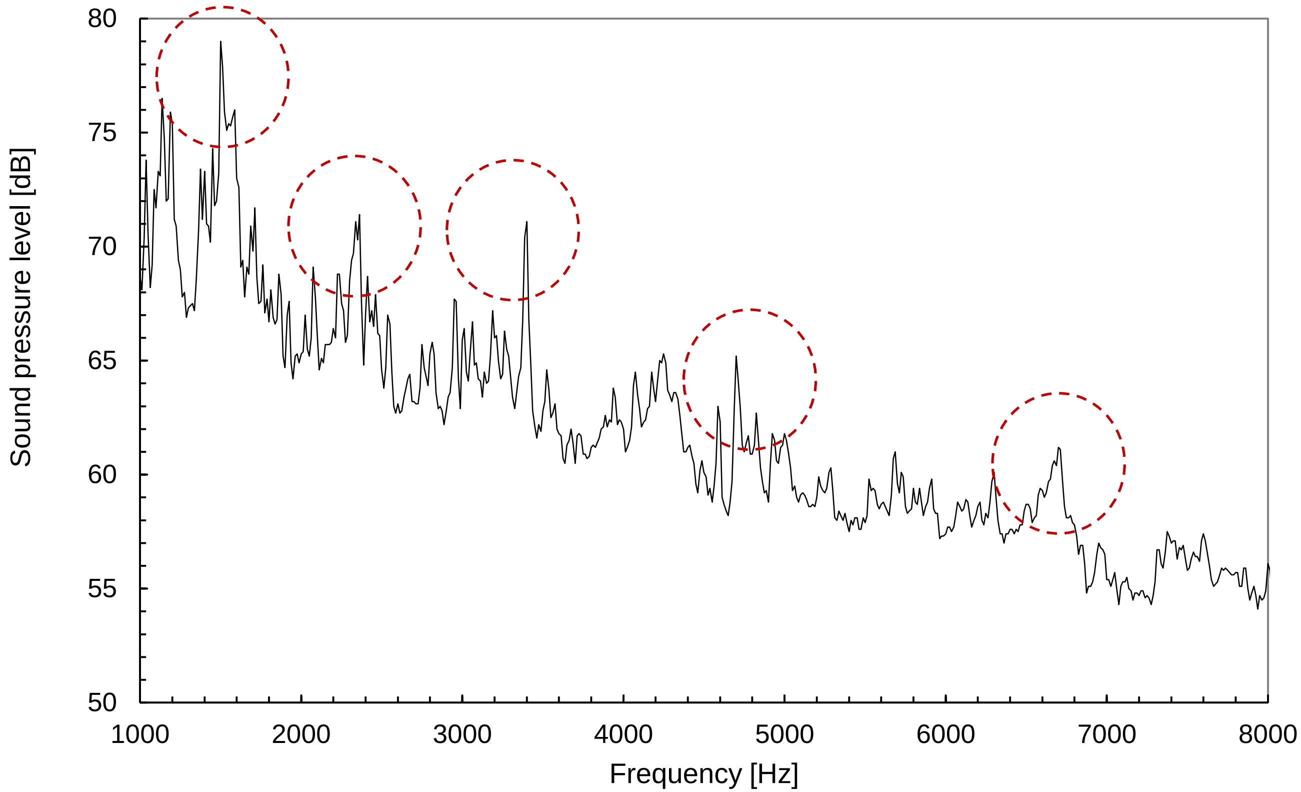
For acoustic finite element problems the pressure field (or displacement field) is discretized. The acoustic pressure-displacement relationship and the element properties are defined by the fluid density and bulk modulus of the domain



Literature data indicate that from an acoustic point of view, the occurrence of only the phenomenon of band gap is insufficient for the effective use of phononic crystals for acoustic barriers

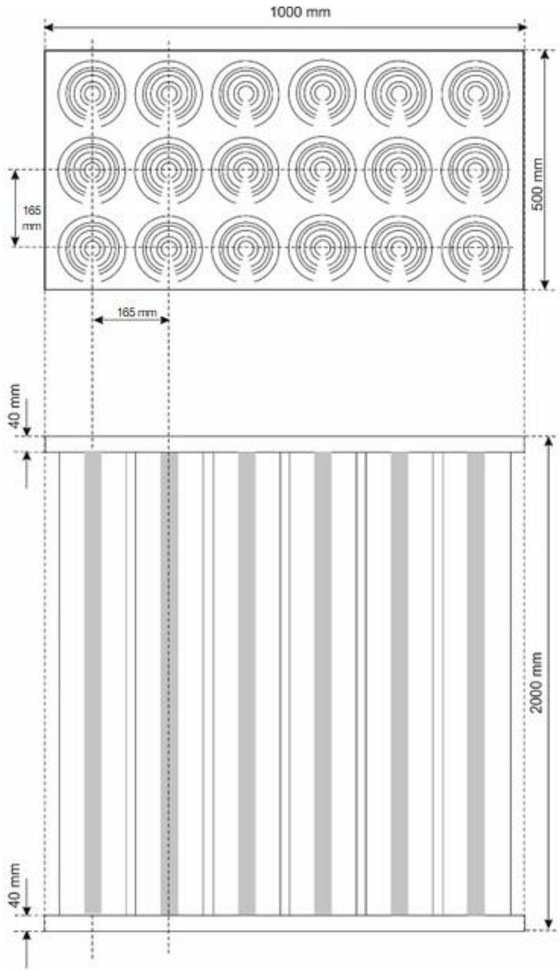
In the field of technical solutions for noise reduction, it is particularly desirable to develop structures with the widest possible frequency range of sound attenuation.

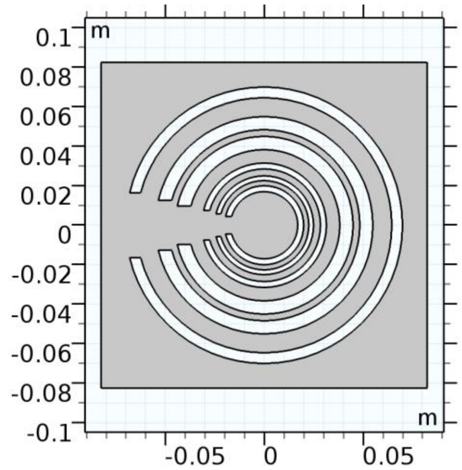
The aim of the research was to develop technical solutions for reducing the noise of stationary devices used outdoors, using phonic sound structures



FFT spectrum of the power generator Elmeco AP1-6000LEA.
Grey circles indicate local maxima of the spectrum.

Physical model





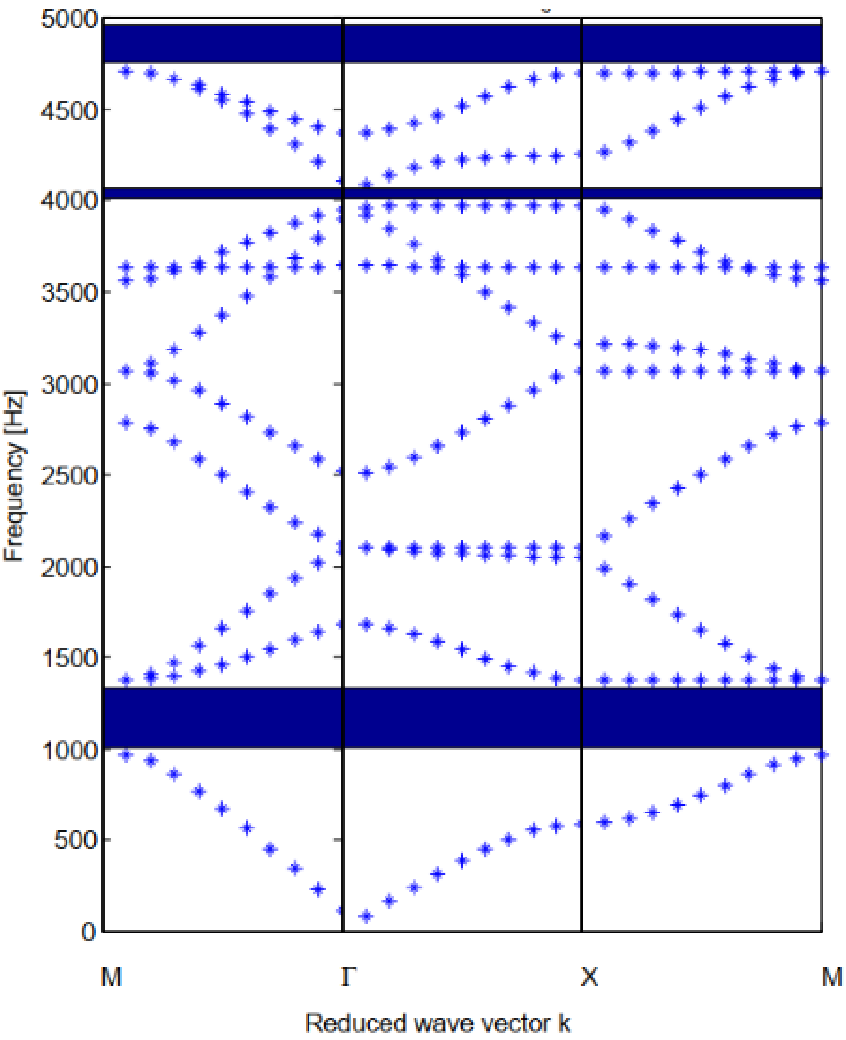
1. PVC-U PN 10 d 140 x 5,4 mm
2. PVC-U PN 16 d 110 x 6,6 mm
3. PVC-U PN 16 d 90 x 6,7 mm
4. PVC-U PN 10 d 63 x 3 mm
5. PVC-U PN 10 d 50 x 2,4 mm
6. PVC-U PN 16 d 40 x 3,0 mm

Physical model

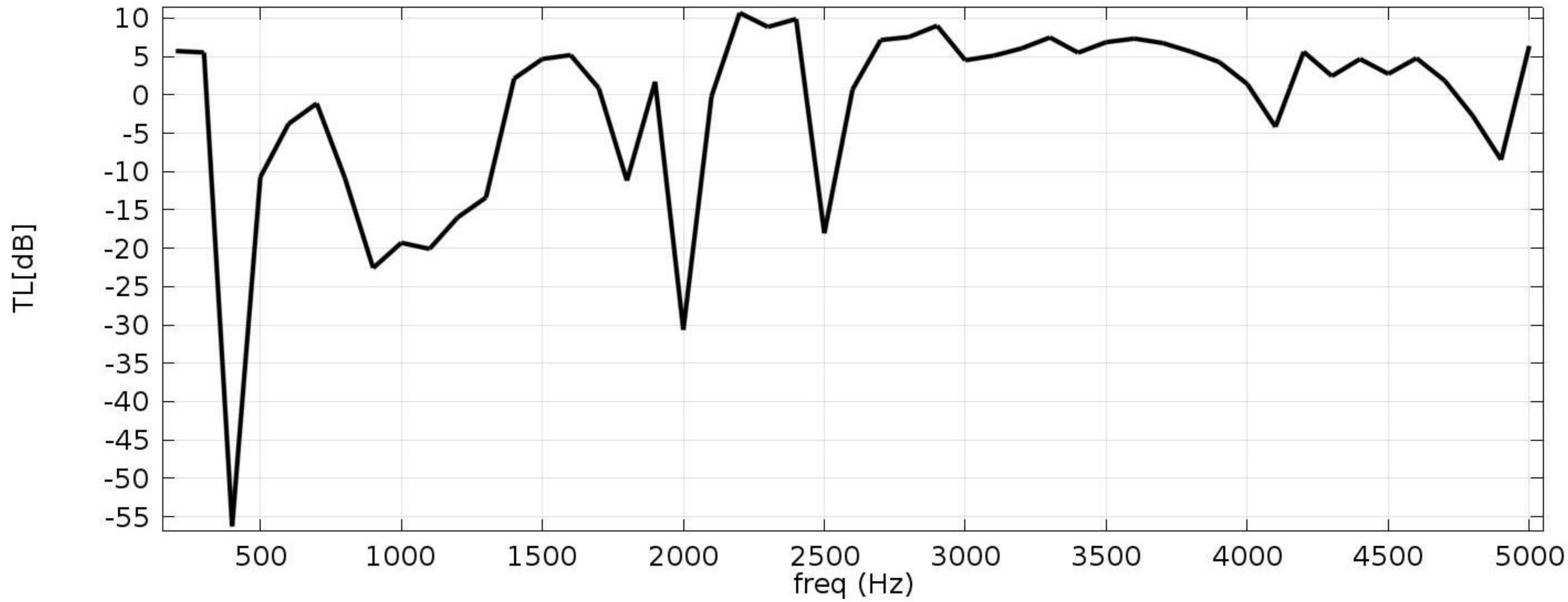
PWE calculations

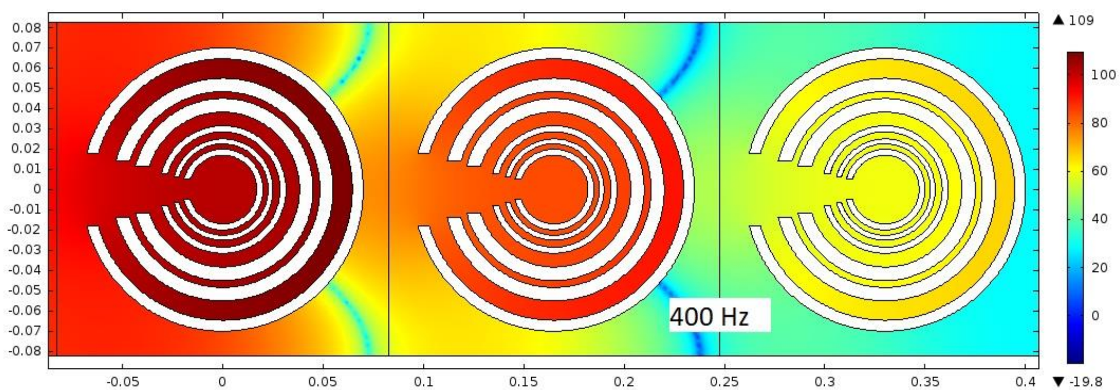
Band structure for air-PVC rod unit cell in the first irreducible Brillouin zone

a = 165 mm
r = 70 mm

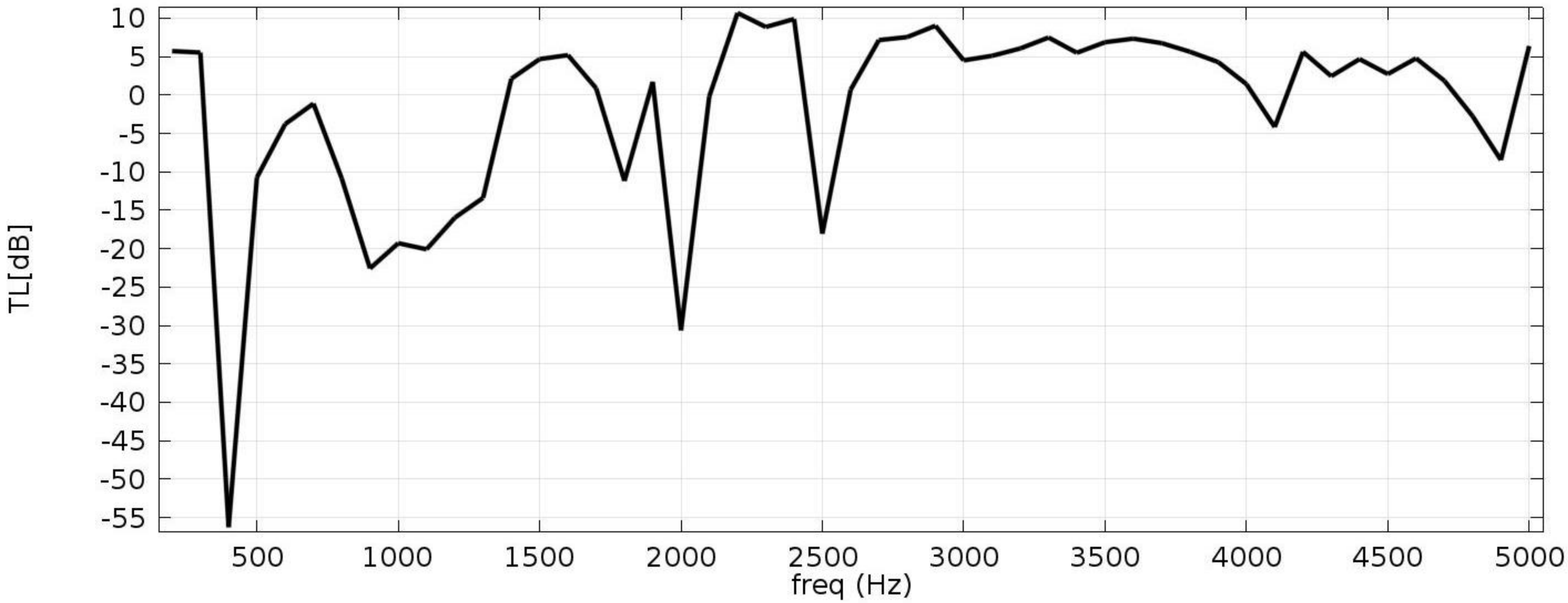


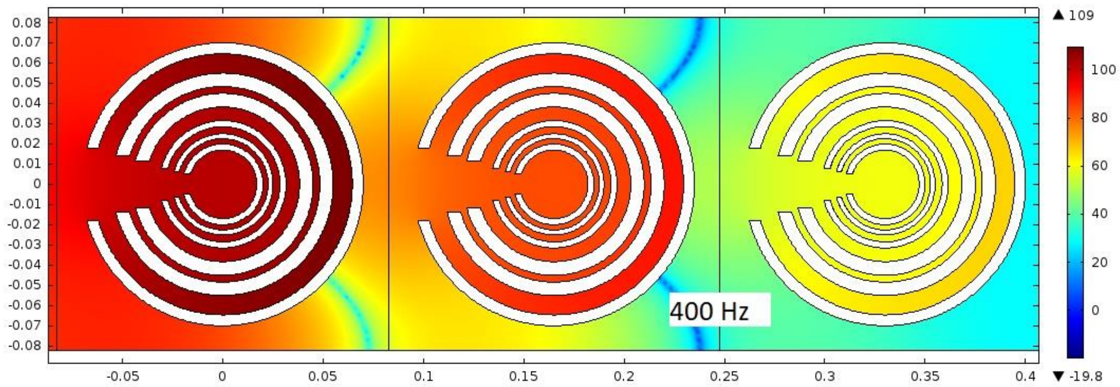
FEM simulation



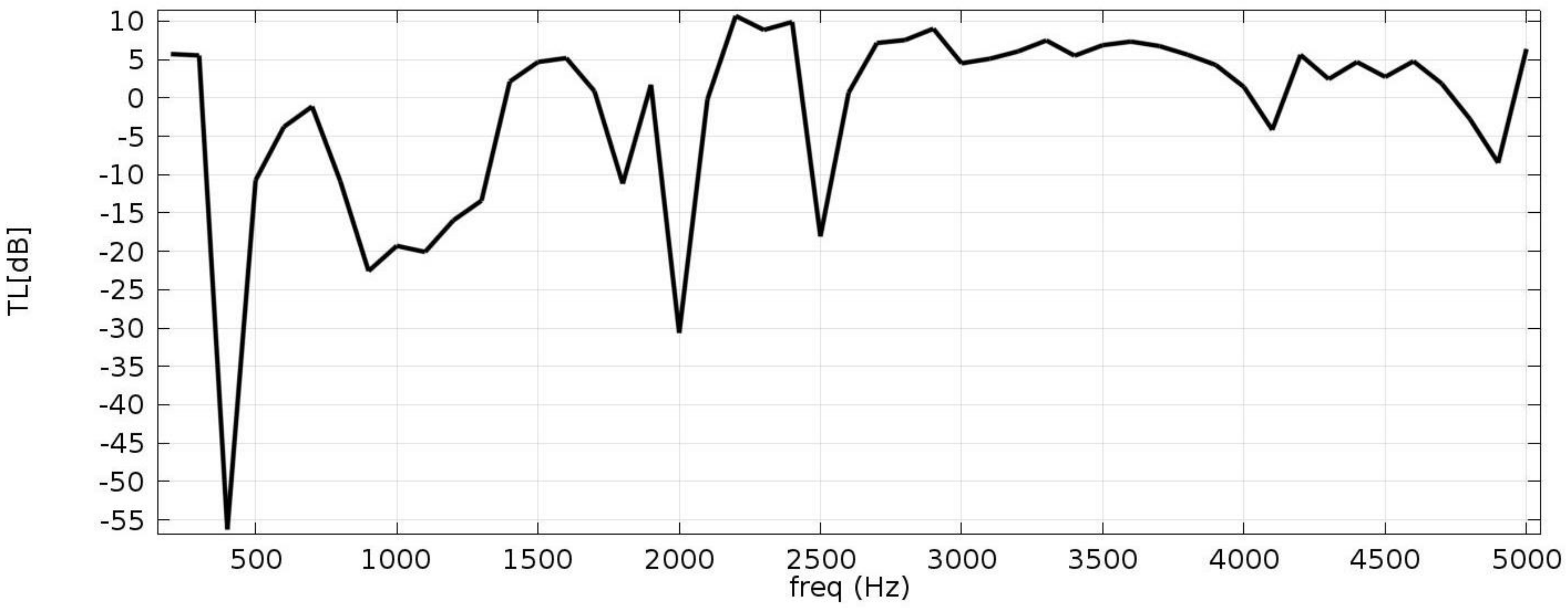


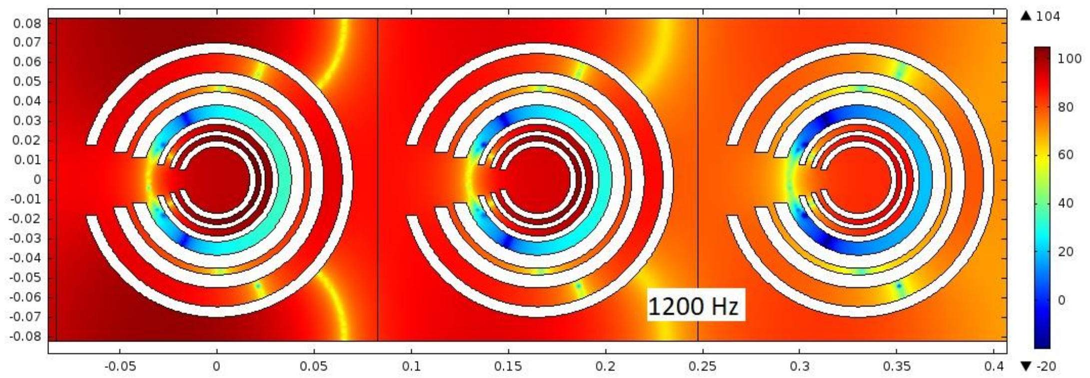
FEM simulation





FEM simulation





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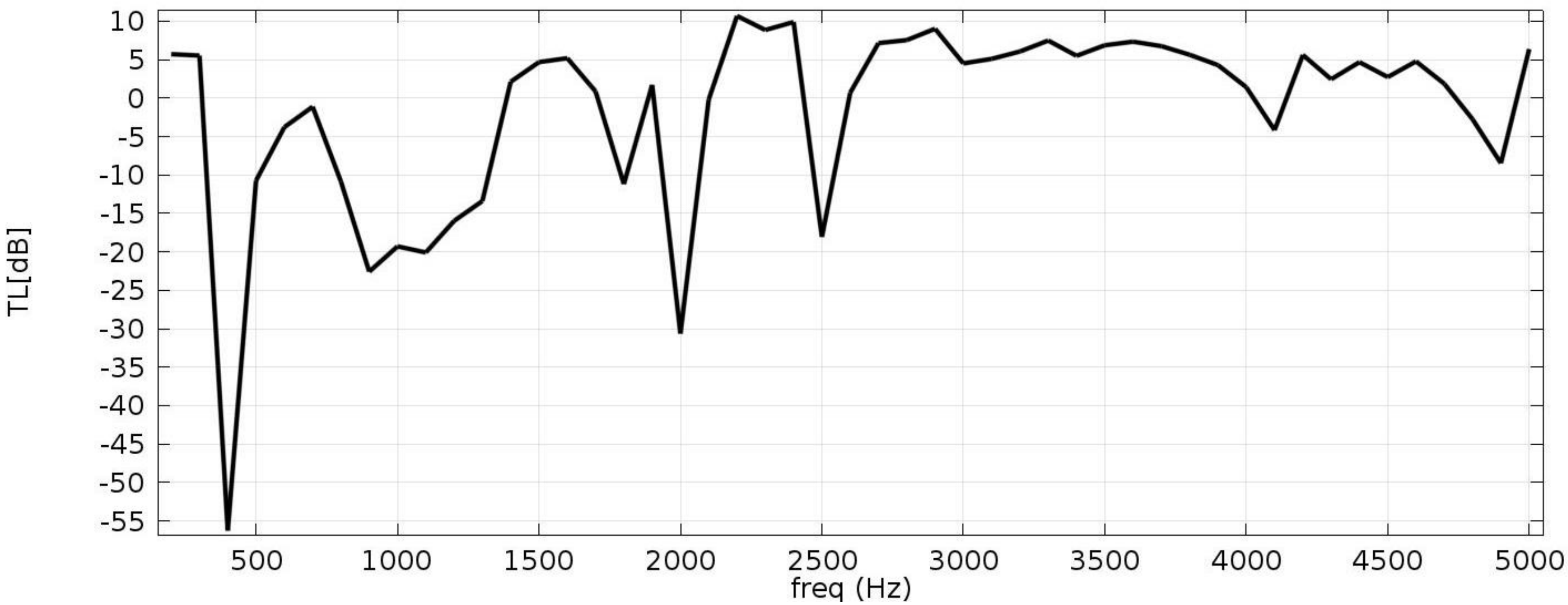
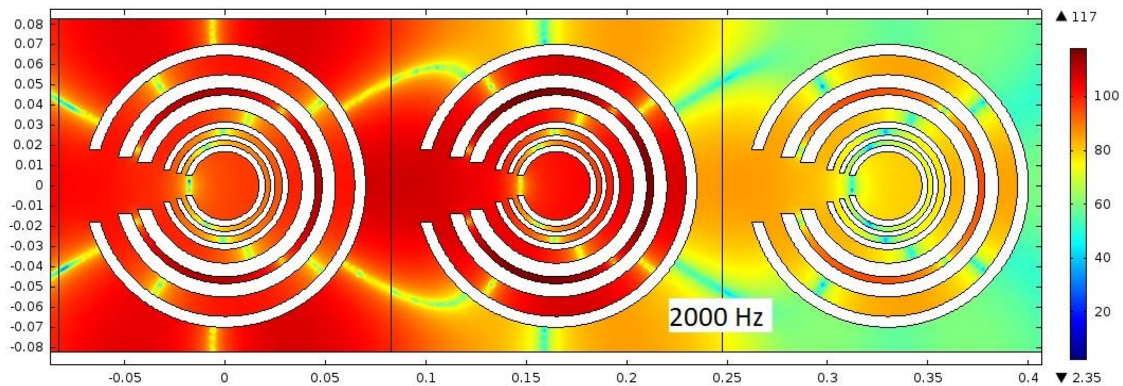
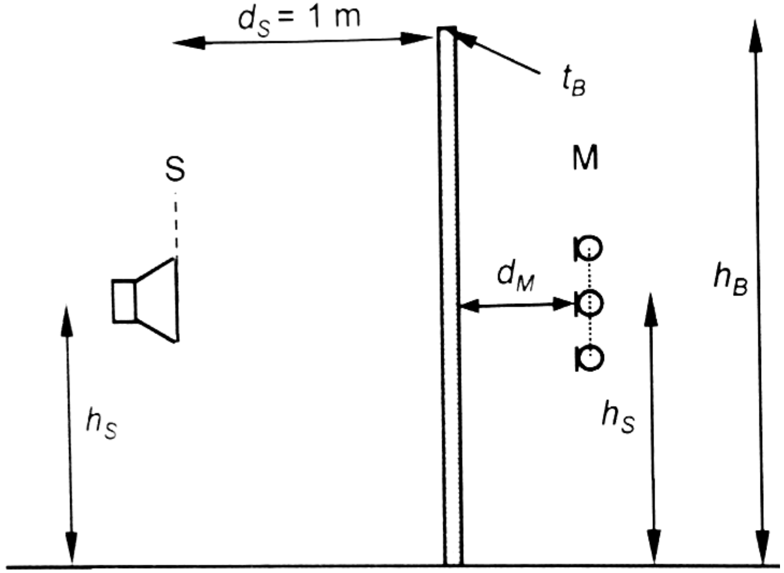
FEM simulation





Sound insulation properties – measurement setup



S – sound source

M – measurement grid

h_s = 1 m

h_B = 2 m

d_M = 0,25 m

$$SI_j = -10\log\left\{\frac{1}{n}\sum_{k=1}^{n}\frac{\int_{\Delta f_j}\left|F[h_{t,k}(t)w_{t,k}(t)]\right|^2 df}{\int_{\Delta f_j}\left|F[h_{i,k}(t)w_{i,k}(t)]\right|^2 df}\right\}$$

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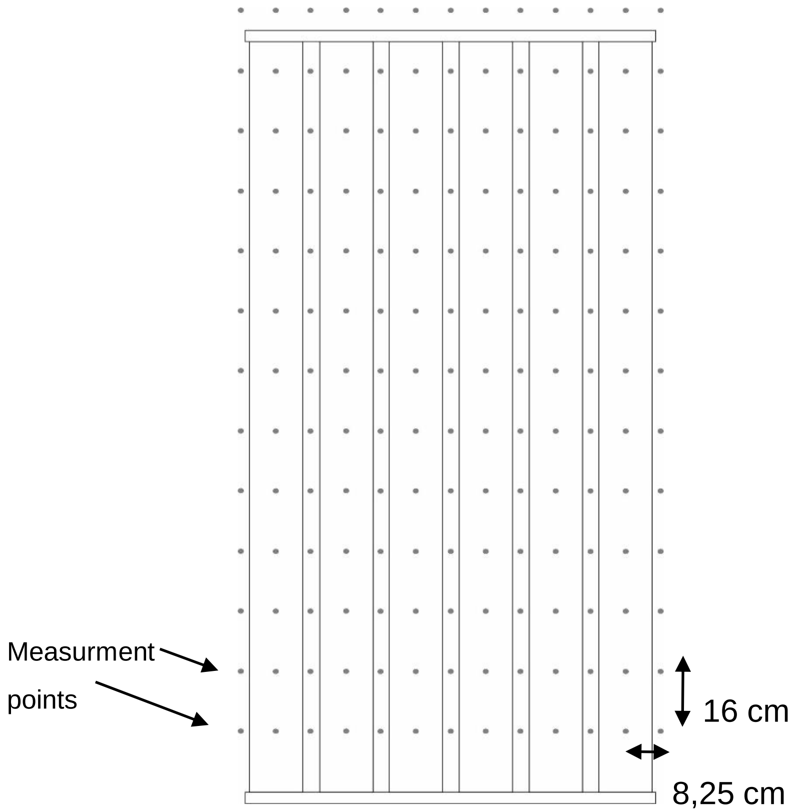
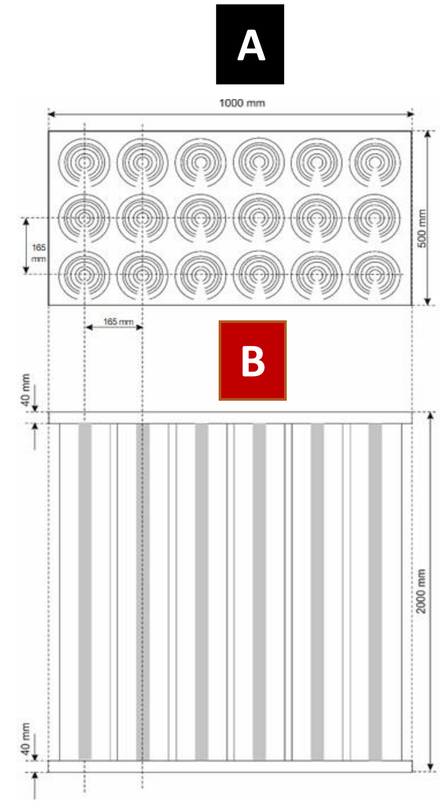
Sound insulation properties – measurement setup



Locations of measurement points in the vertical plane

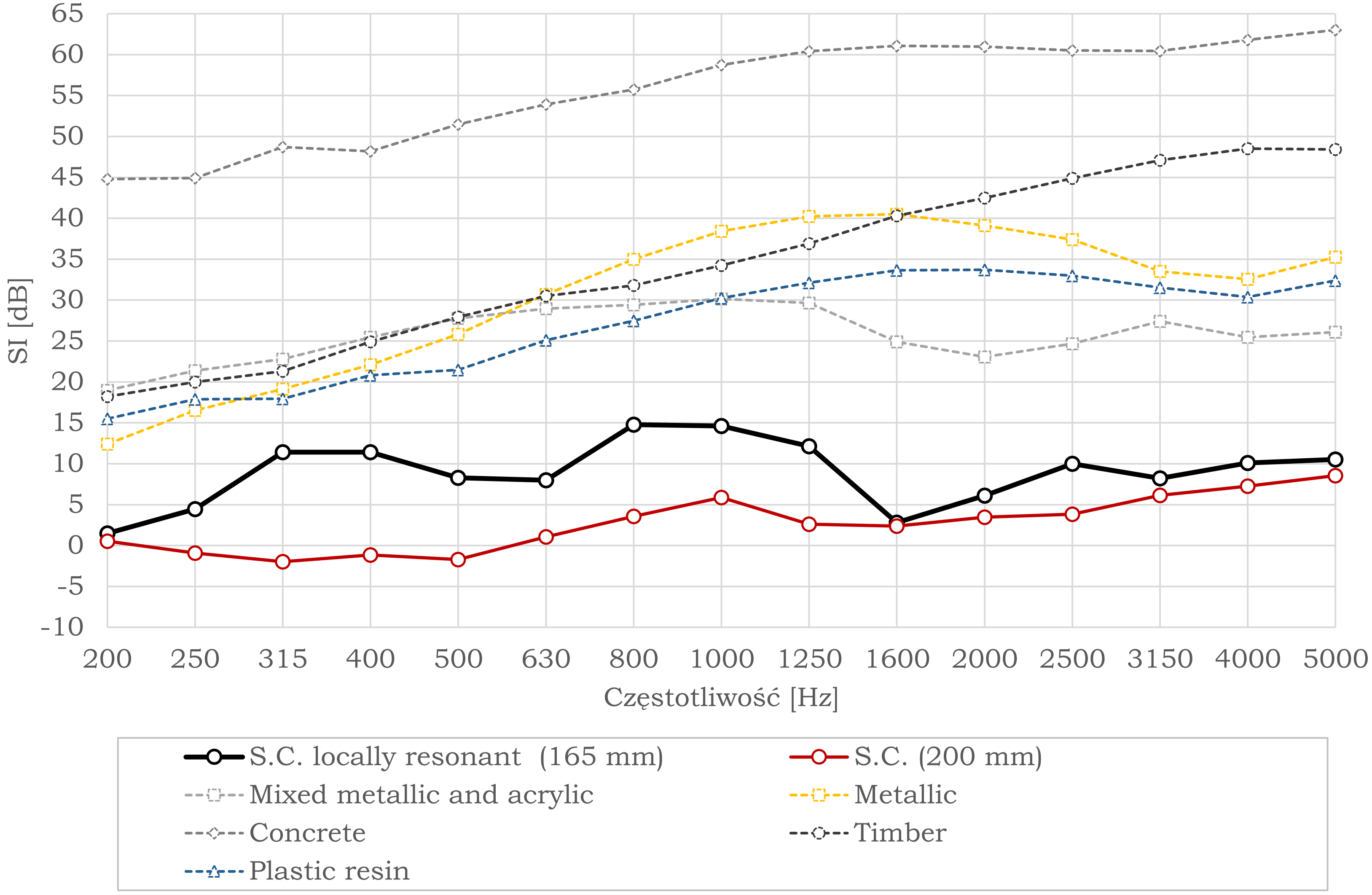
Additional measurements (with and without the barrier) of sound pressure level with the sound level meter (class 1) were carried put over 169 measurement points in vertical plane parallel to the barrier's surface with d_M = 0,25 m.

Sound insulation properties



Measurement result of sound insulation of real-sized sonic crystal noise barrier made of six concentric resonators and a SC with 3 rows of cylinders

Sound insulation properties



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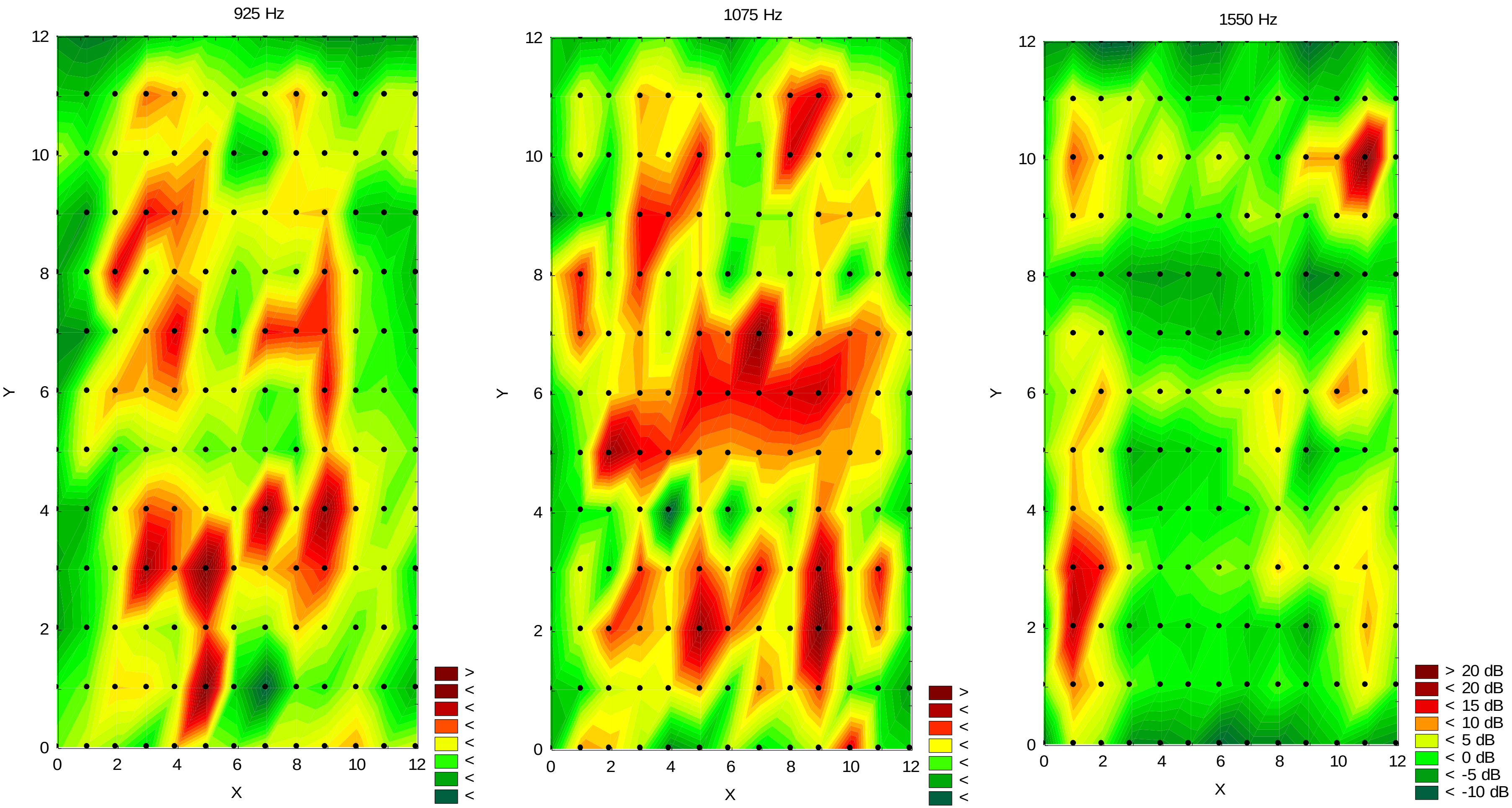
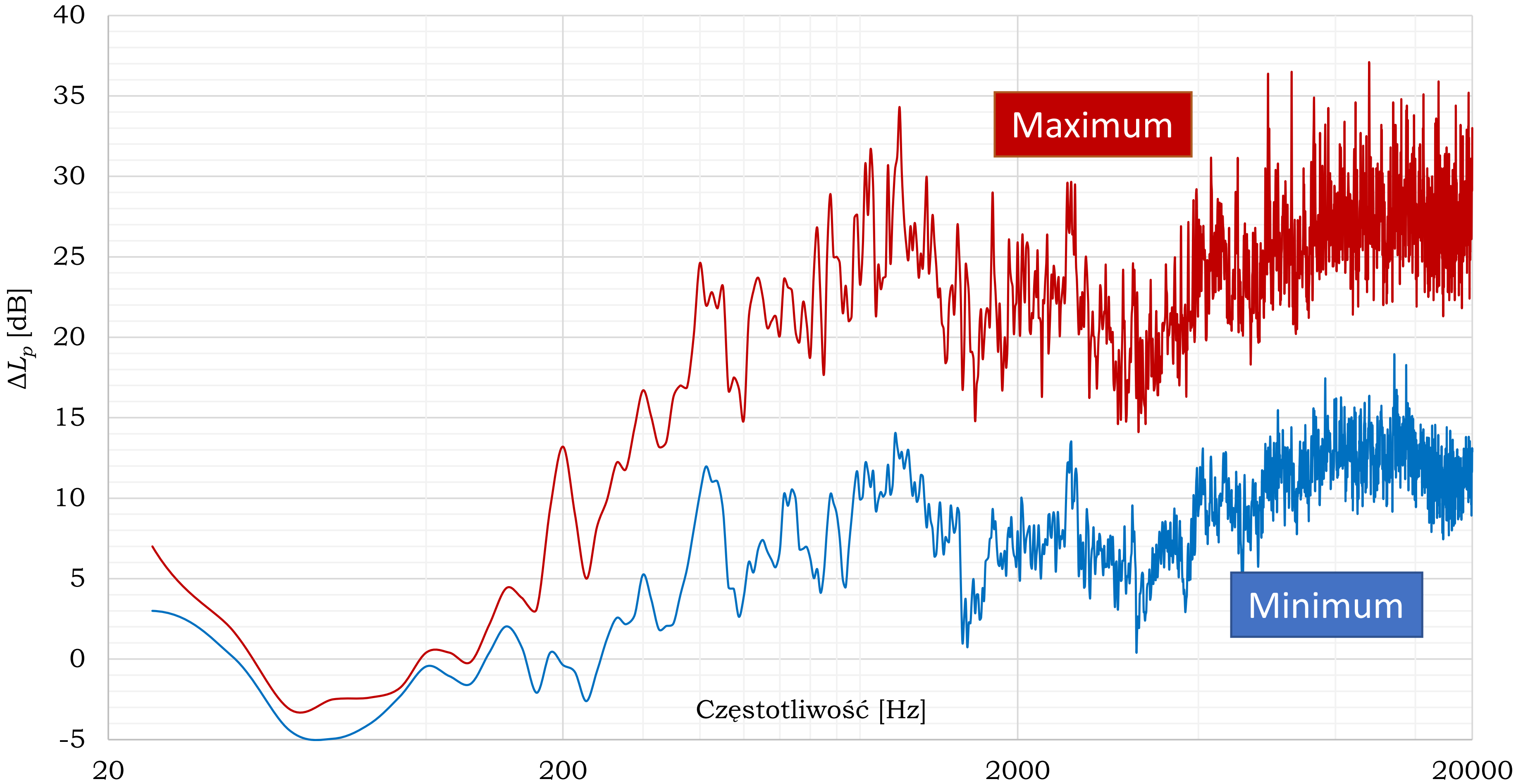
Sound insulation properties



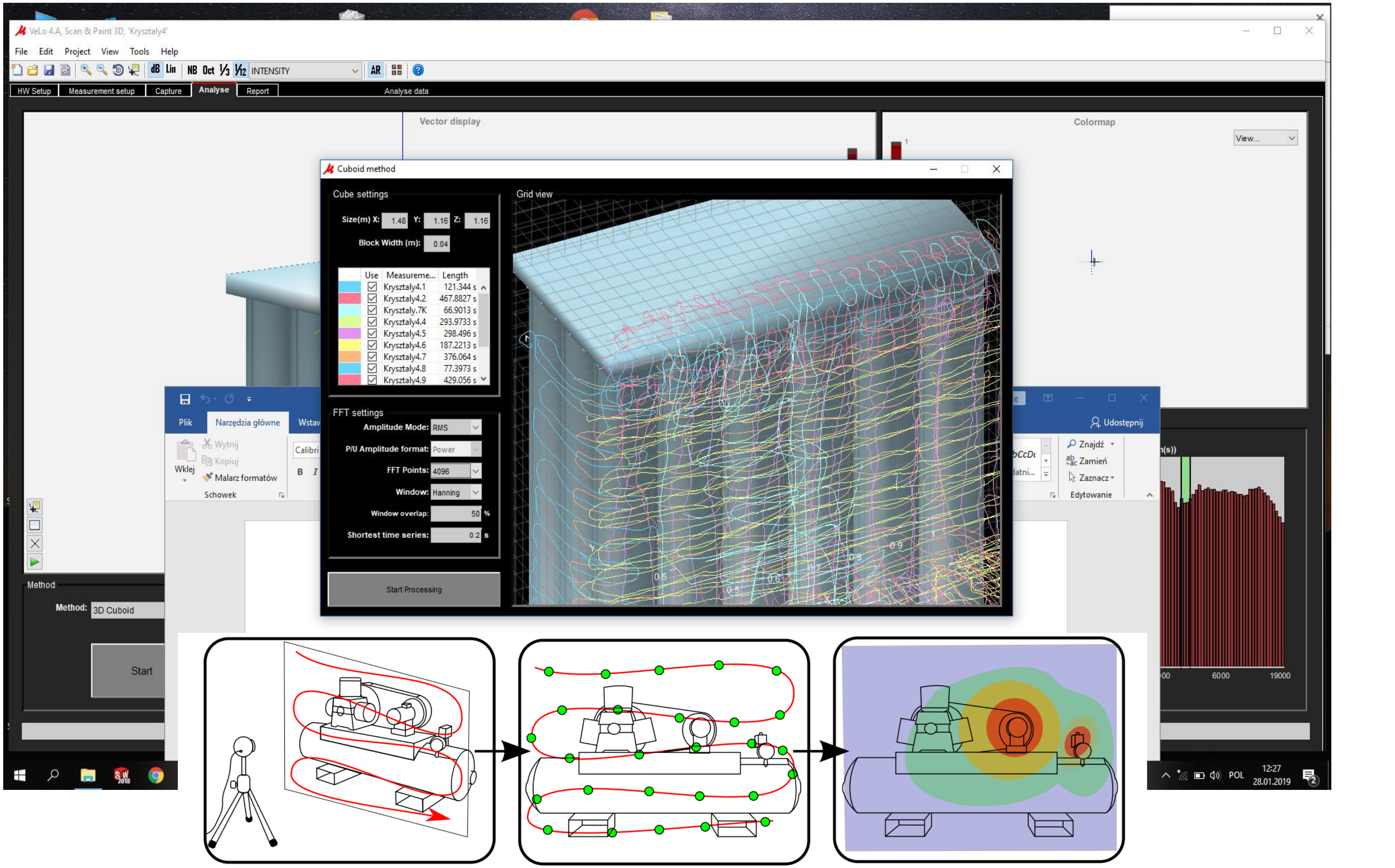
Distribution of the reduction of the sound pressure level at the measuring points

Sound insulation properties



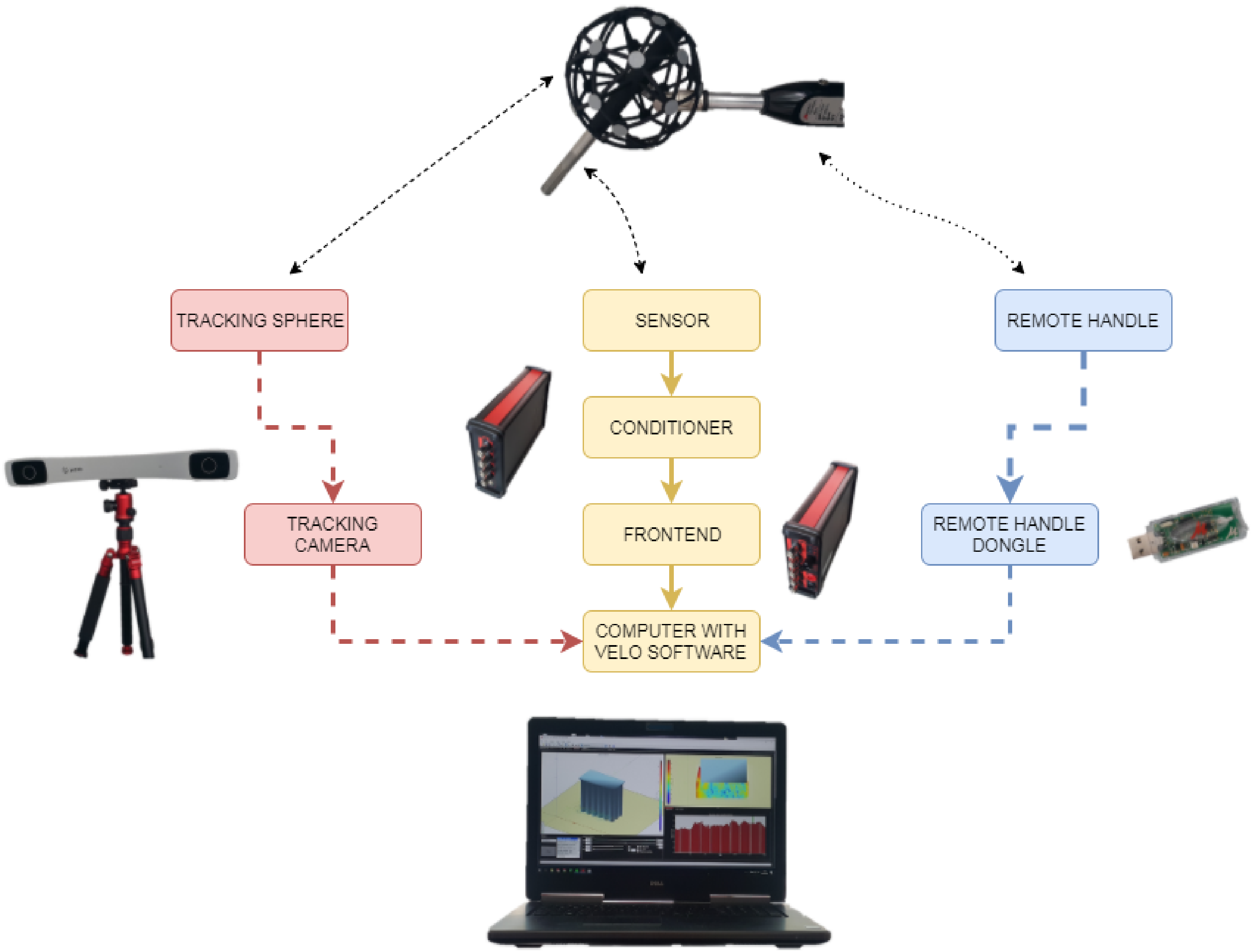
Reduction of the sound pressure level at the measuring points

Sound intensity acquisition in 3D

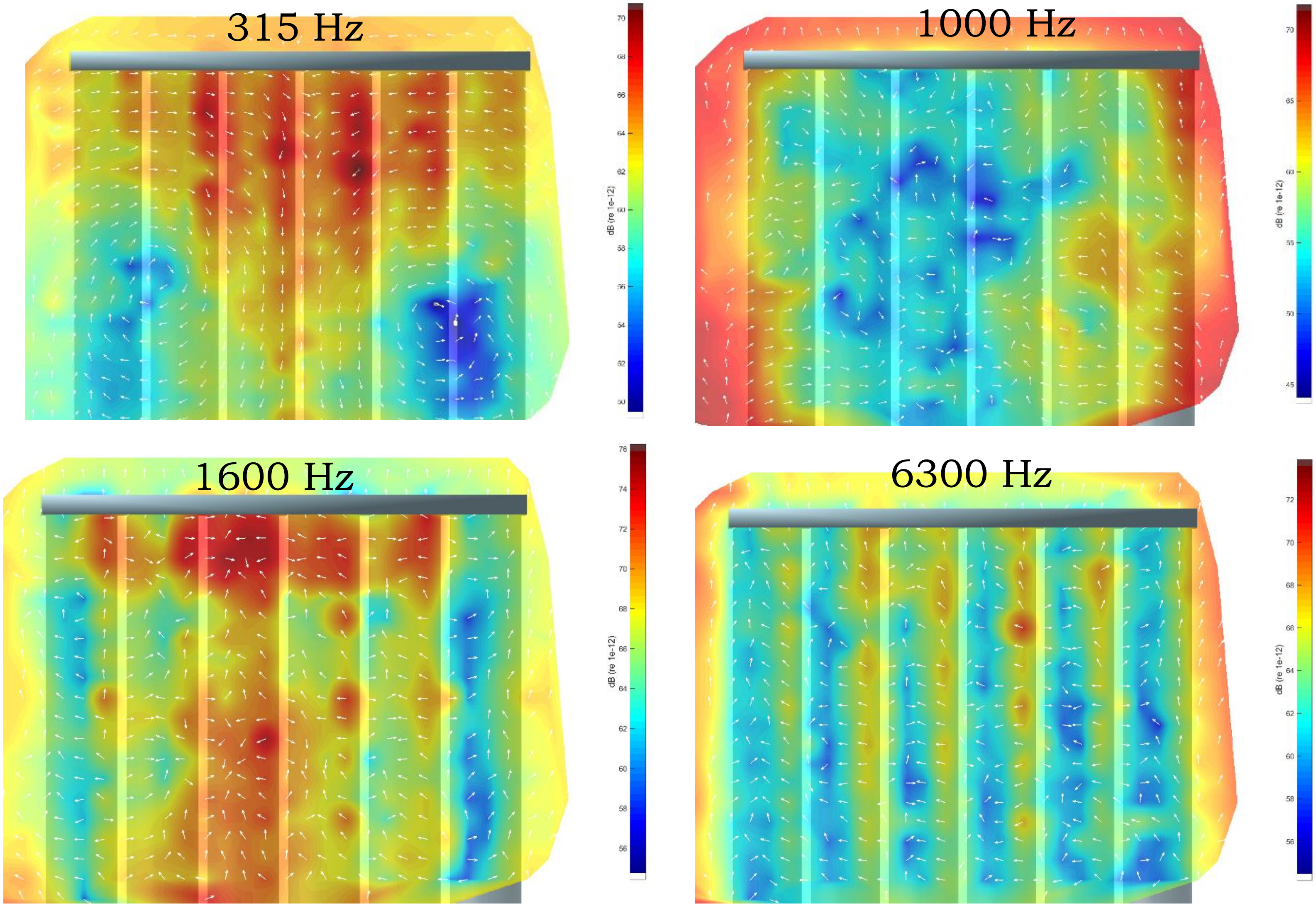


Microflown Scan & Paint 3D.

Sound intensity acquisition in 3D

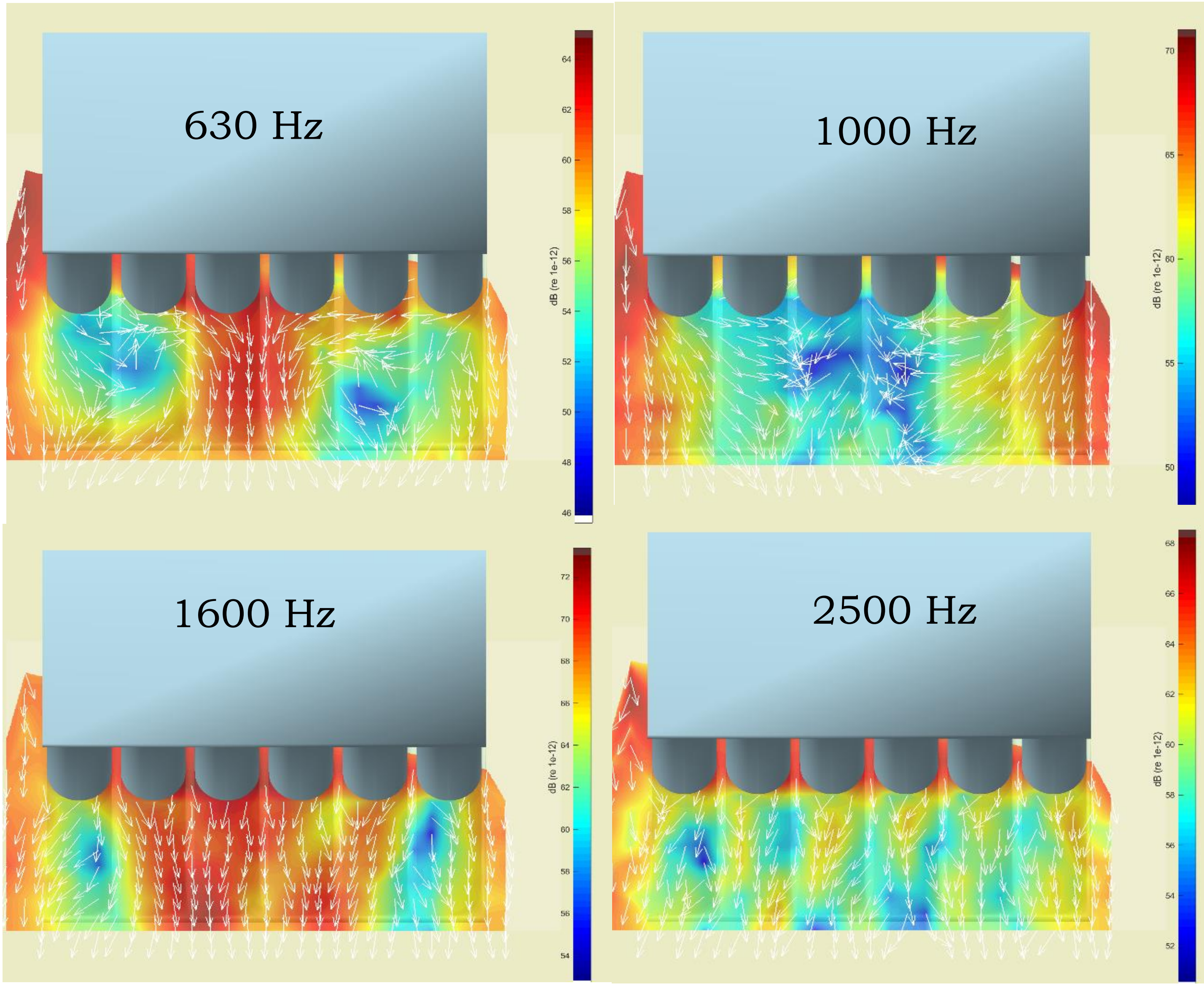


Sound intensity distribution



Distribution of the sound intensity vector in the vertical measuring plane

Sound intensity distribution



Distribution of the sound intensity vector in the horizontal measuring plane

CONCLUSIONS

- A **scan-based measurement technique** to characterise the sound energy distributions in is presented. The use of a 3D *p-u* intensity probe along with a 3D tracking system enables to acquire high resolution sound intensity maps
- SC barriers present a very good acoustical response, in view of the standardization results obtained, showing that they can compete acoustically with classical barriers. However scan-based measurement technique showed **differentiated efficiency of sound insulation** in the measurement plane depending on the position and frequency
- Literature analysis suggests the need for **developing unified methods** for assessing the effectiveness of acoustic insulation of barriers based on sonic crystals
- The **visualization of sound field** can be helpful not only for characterizing SC noise barriers but also to understand how the acoustic field is excited, potentially helping to improve the acoustic characteristics of sonic crystals.

Conference

Warsaw, 15 October 2019

Novel technological innovations for occupational safety and health

Acoustic barriers based on locally resonant sonic crystals

THANK YOU FOR YOUR ATTENTION

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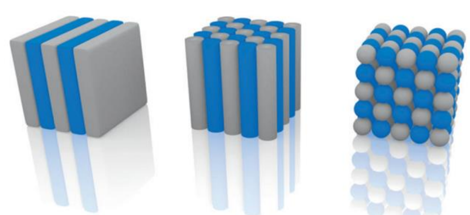

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