Experimental methods to evaluate the effective acoustic performance of screen made in metamaterials

G. Amadasi[1], A. Bevilacqua[2], G. Iannace[3]; A. Trematerra[3]

[1]SCS-ControlSys - Vibro-Acoustic, Padova, Italy
[2] Department of Industrial Engineering, University of Parma, Parma, Italy
[3] Department of Architecture and Industrial Design University of Campania «Luigi Vanvitelli", Aversa, Italia

Topics

- Introduction
- History
- Applications
- Test case
- Conclusions

Introduction

This paper describes different setup for the determination of IL of screen made in metamaterials.

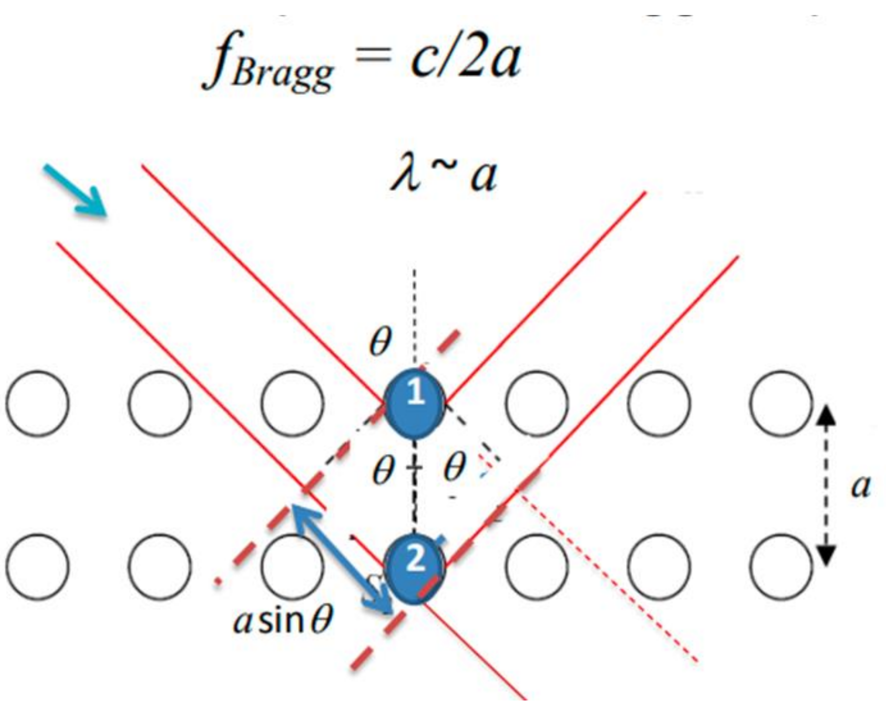
The IL method focuses on fixed-boundaries conditions of the screen sample as it is considered as a single element.

The IL determination is based on either sound pressure and sound intensity measurements.

- The term metamaterials was coined nearly a decade, the word metamaterial is made of two words: meta and material.
- The prefix “meta” originates from the Greek word for “after” or “beyond,”
- Metamaterials are artificial structures designed and built to control the propagation of the waves.
- So the metamaterials are new materials obtained by the interaction of artificial objects and geometric structures of regular shape.
- The study of metamaterials represents a new field in the applied acoustics.
- The sound attenuation is due to the interference of waves in the band of frequencies and the propagating wave has a decaying amplitude, which causes the sound attenuation to take place in the band gap region.
- When an electromagnetic wave (light wave) passes through a periodic structure, photonic band gaps are formed.
- Therefore, there are certain frequencies of light that are allowed to pass through the structure and certain frequencies are restricted.

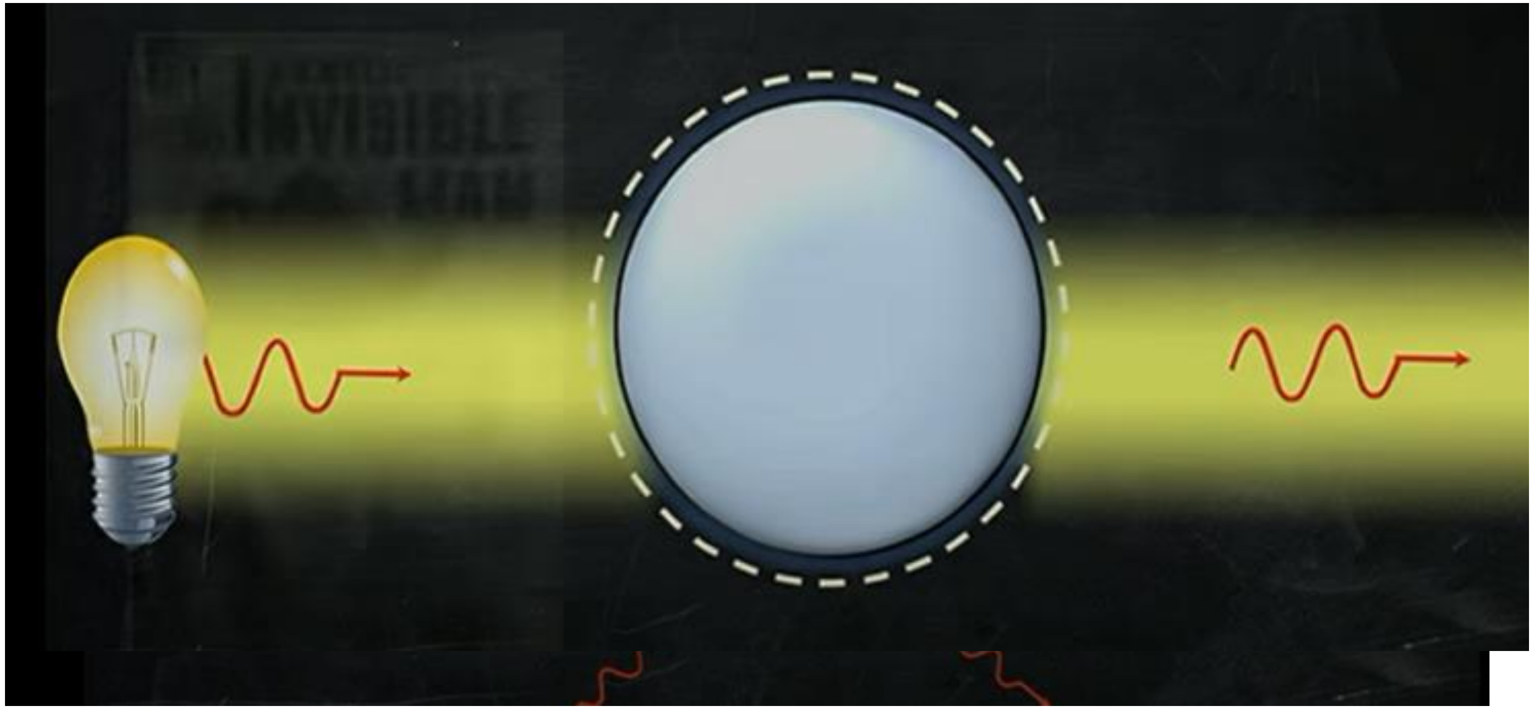
- The metamaterials artificial materials with periodically structured.
- Due to the periodic arrangement of scatterers, metamaterials have a unique property of selective sound attenuation in specific range of frequencies.
- This range of frequencies is known as the band gap, and it is found that sound propagation is significantly reduced in this band gap region.
- The attenuation of the sound propagation is obtained by using the interaction between regular geometric shapes and specific dimensions.
- The periodic distribution of materials involves, in the propagation of waves, constructive and destructive effects due to interference as a function of the frequency and therefore of the wavelength of the incident radiation.

- The waves in their propagation in a medium (air), interact with these components and, since the dimensions of the elements are smaller compared to the wavelength, they can assume specific physical properties, such as the negative elastic modulus, the negative mass density, the negative refractive index.
- The properties of the metamaterials are due to the geometric structure and not to its chemical composition of the same.
- The first studies in this field date back to over half a century ago with the works of V. Veselago and J. Pendry, and these studies were directed to the control of the propagation of electromagnetic waves, therefore for small wavelengths of the order of micro meters.

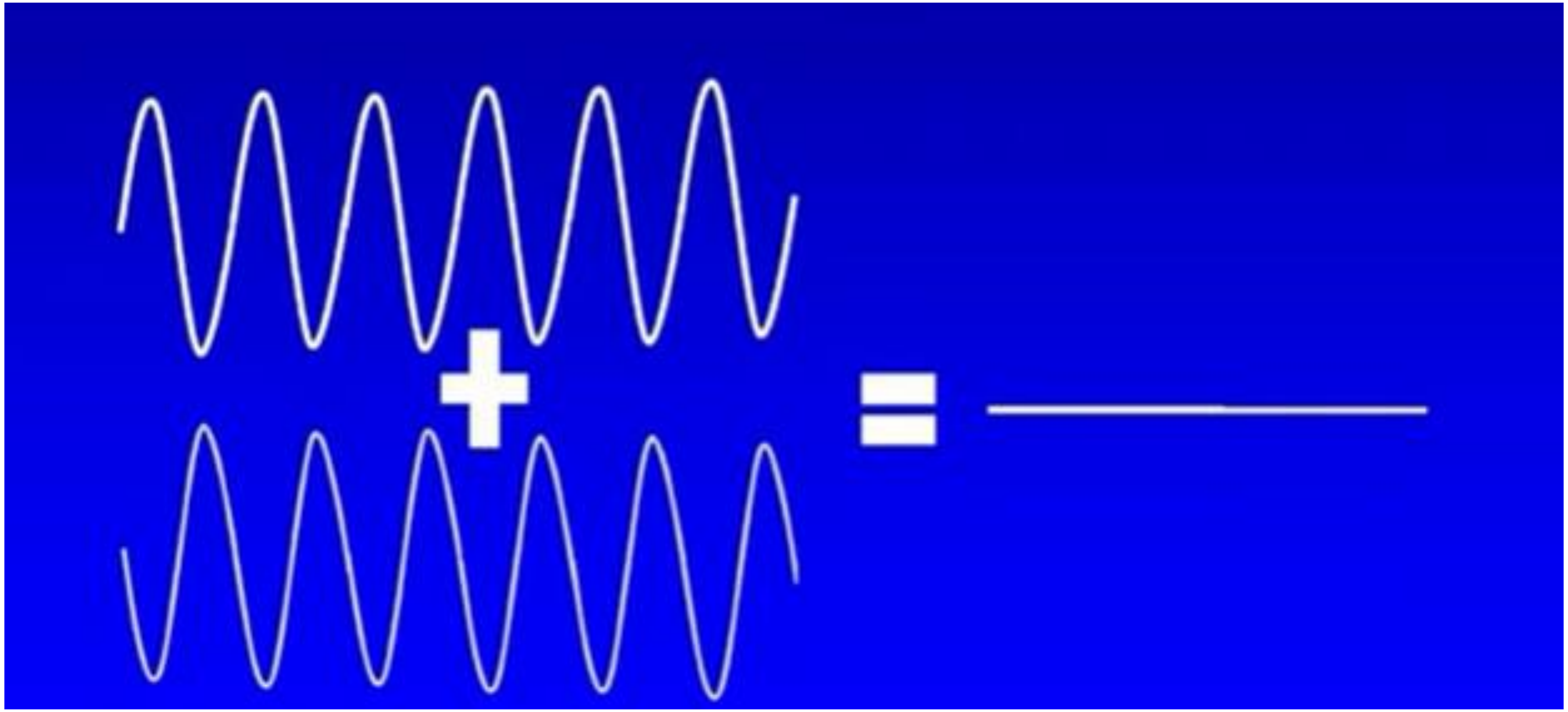


- The basic principle of incident sound attenuation is based on the Bragg frequency.
- The Bragg attenuation frequency is applied in the electromagnetic field, but can also be applied in the applied acoustics field.
- The frequency at which the theoretical attenuation occurs is calculated with the following relationship:
  - $f_{Bragg} = c / 2*a$
- where c (m/s) is the speed of sound in air, while "a" is the distance between the solid elements considered

All starts with the search for an invisible material. By covering the object with a film that forces light to pass over the surface without reflecting it.

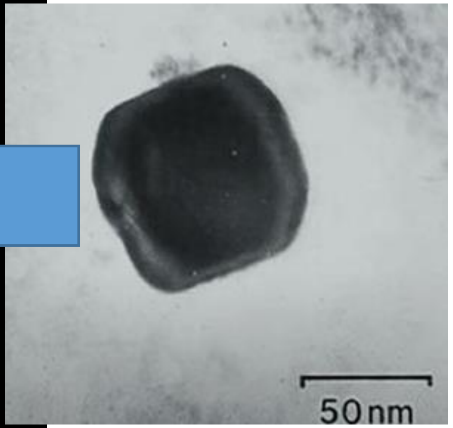


- The periodic distribution of materials involves, in the propagation of waves, constructive and destructive effects due to the effects of interference as a function of the frequency and therefore the wavelength of the incident radiation.
- Two out-of-phase waves that add together result in a wave of zero amplitude and therefore destructive interference.

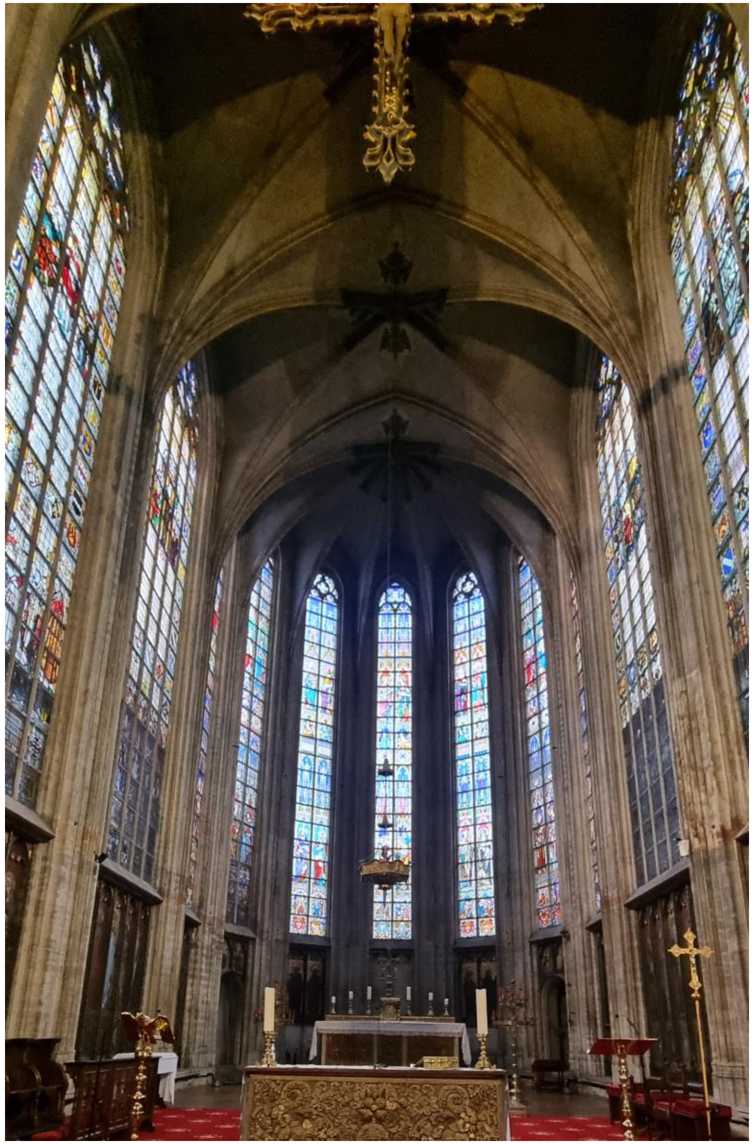


Lycurgus Cup

- The Lycurgus Cup is a glass cup from the Roman era, dating back to the 4th century and preserved in the British Museum in London, showing the mythical Lycurgus, king of Thrace.
- The cup is constructed of glass and displays a different color depending on the way light passes through it: red when lit from behind and green when lit from the front.
- The effect is achieved by contaminating the glass with small proportions of gold and silver nanoparticles dispersed in colloidal form throughout the glassy volume.
- The exact process used remains unclear and it is likely that it was not well understood or controlled even by the manufacturers: the effect was accidentally produced by contamination with gold and silver nanoparticles. .

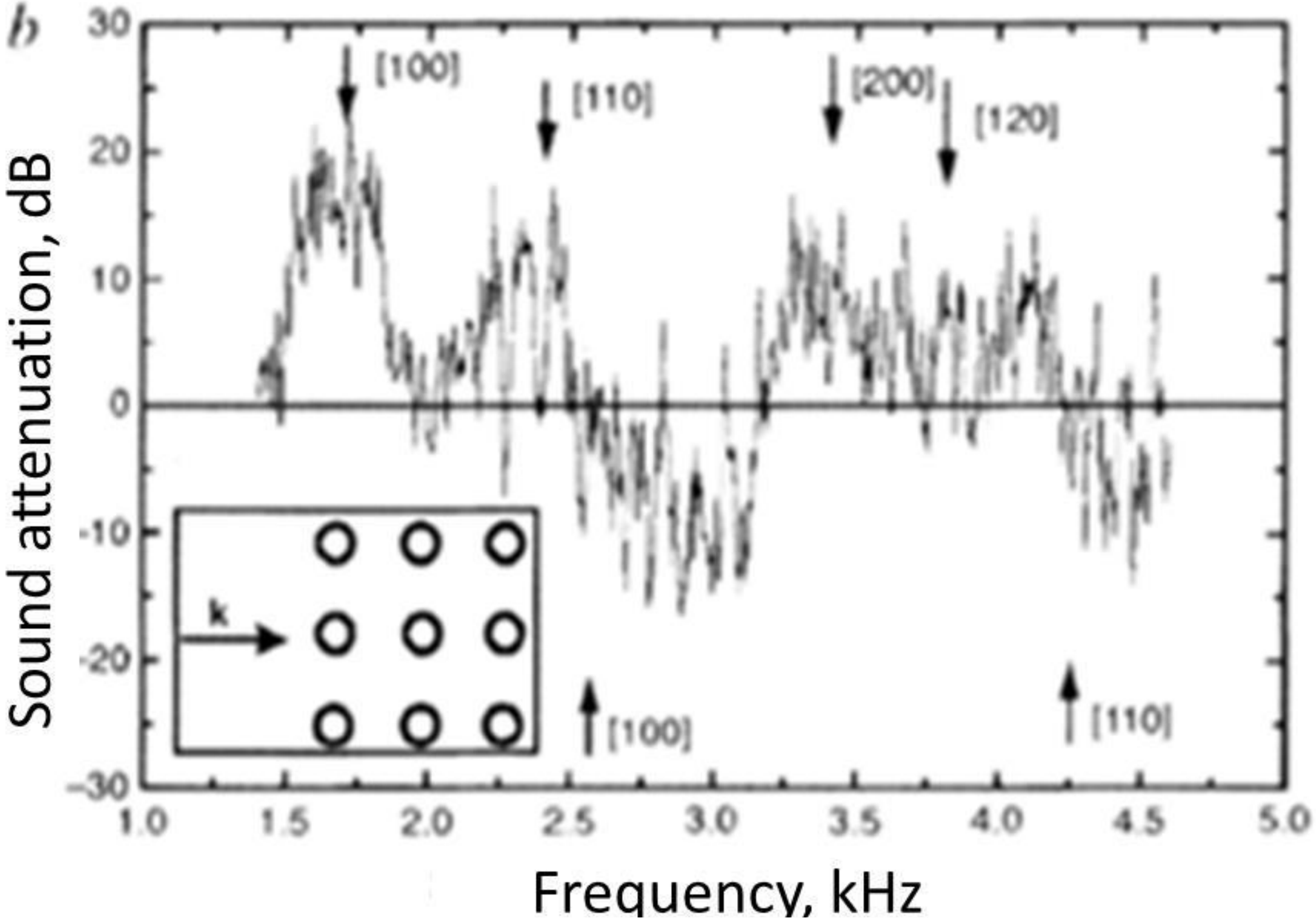

50 nm

Stained glass windows of the cathedrals of Northern Europe

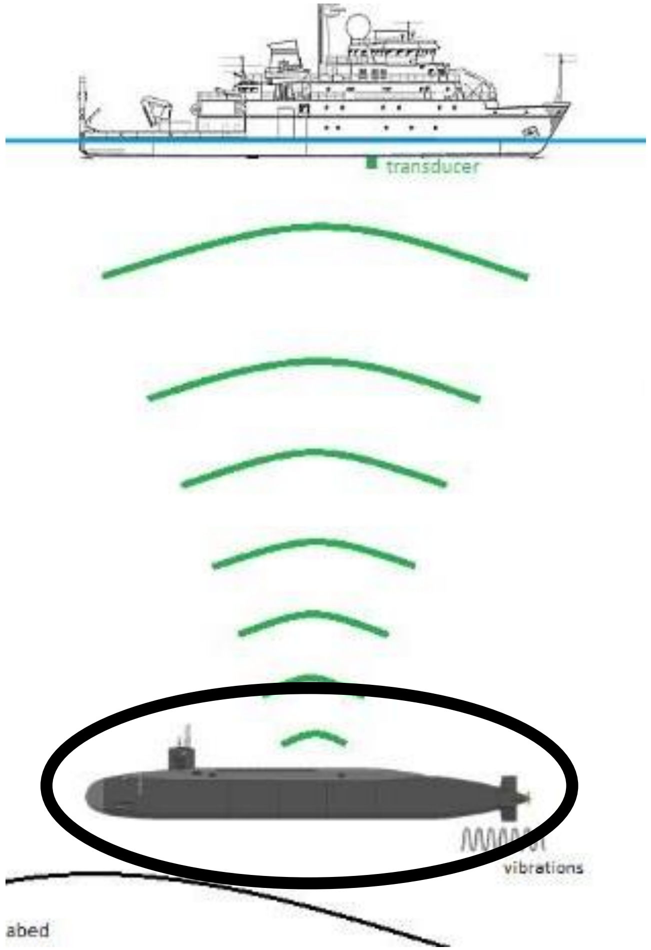


Sempere «L’Organo»

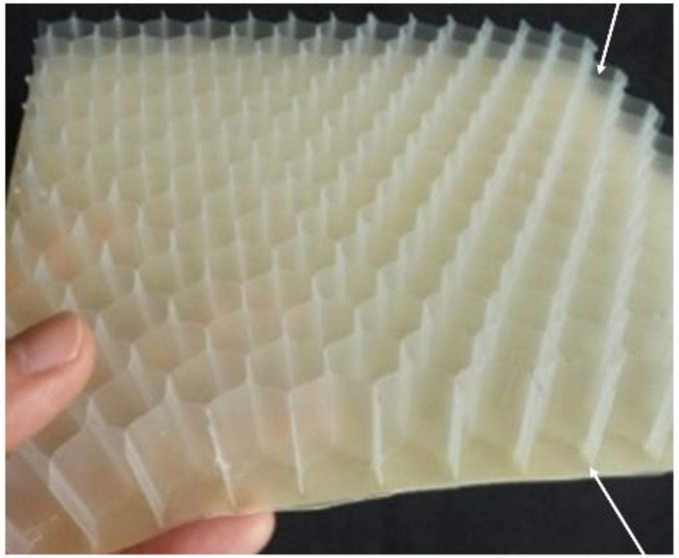
Regular geometry with steel bars (diameter 3 cm) with a pitch of ten centimeters; when sound propagates through this structure, some frequency components are attenuated compared to others, in the case in question at the frequency of 1,670 Hz there is a sound attenuation which corresponds to a component of destructive interference.

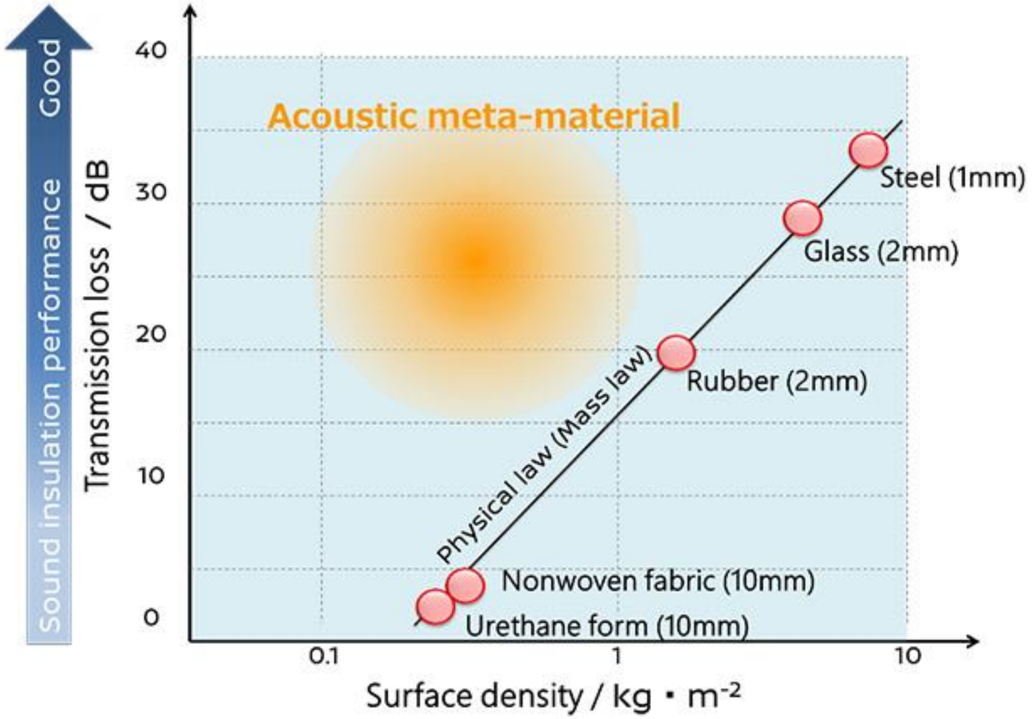

b
[100]
[110]
[200]
[120]
[100]
[110]
k
30
20
10
0
-10
-20
-30
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Sound attenuation, dB
Frequency, kHz

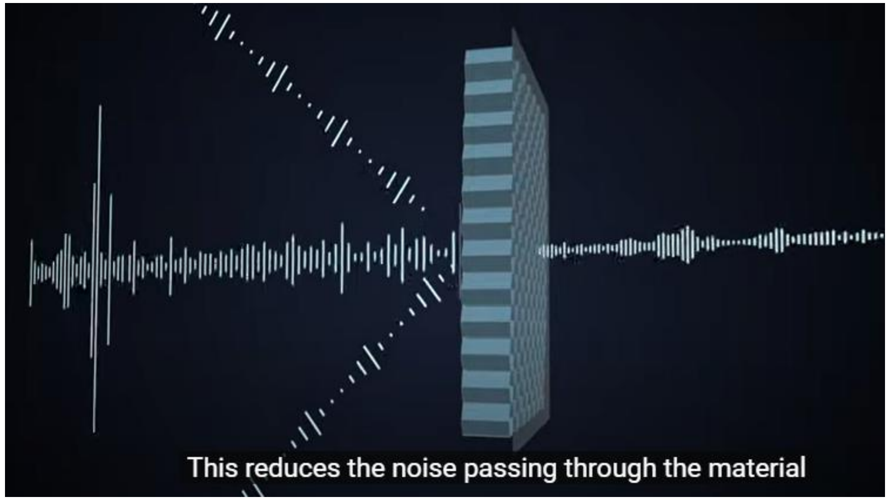
- From a historical point of view, however, the first applications of matamateriali date back to the period of World War II, some German submarines were covered with periodic rubber structures to reduce the effects of the acoustic waves emitted by the sonars of English ships.
- This structure was defined Alberich as the name of a warrior from a medieval Teutonic legend who fought against enemies wearing an invisible cloak.



Nissan automotive





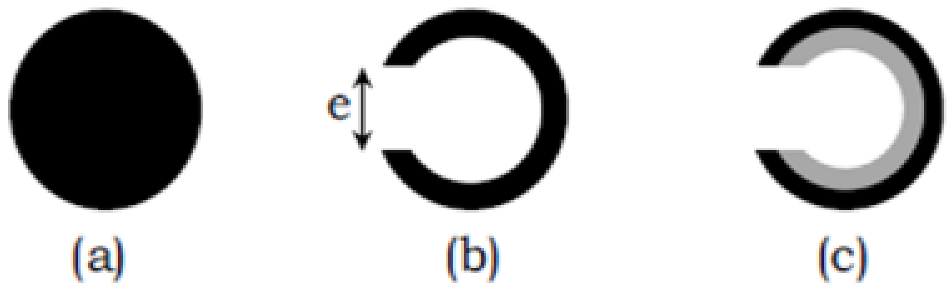


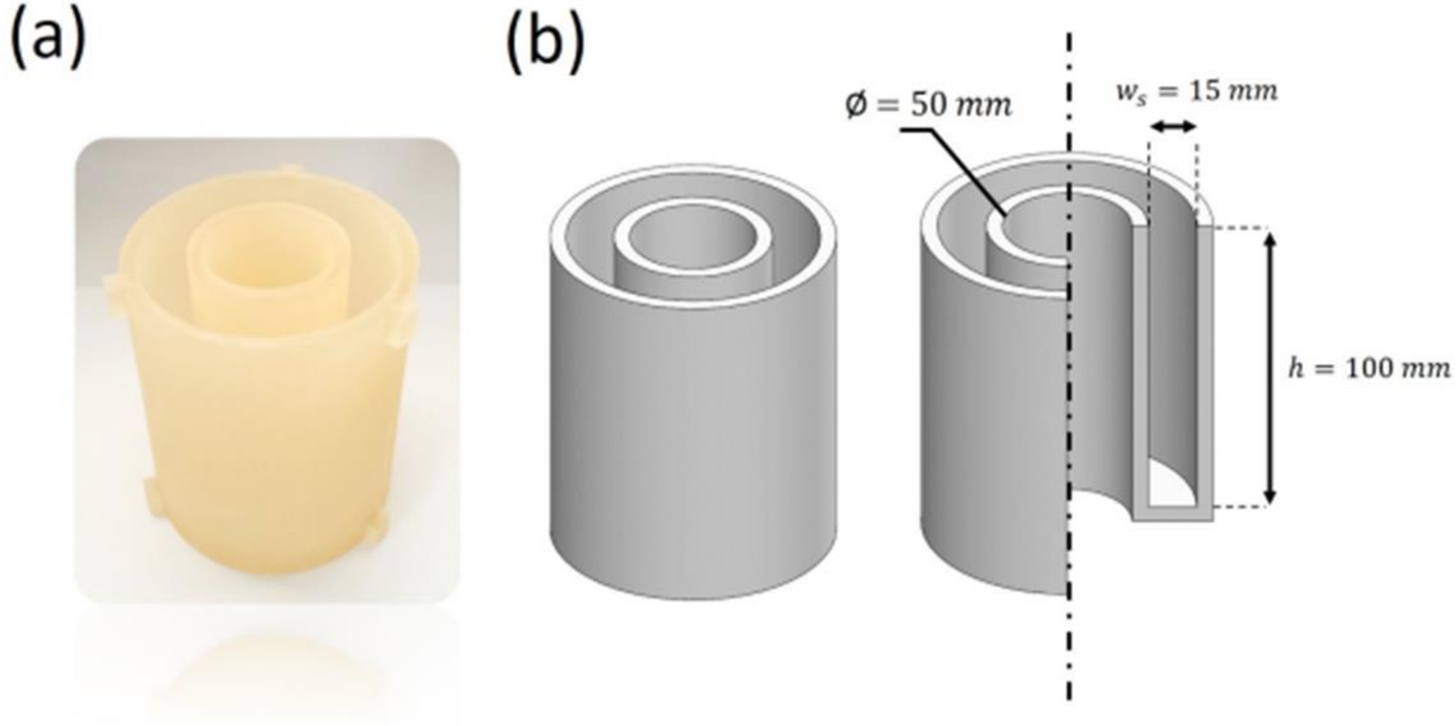
Noise attenuation with traditional material

Noise attenuation with metamaterial

A B C

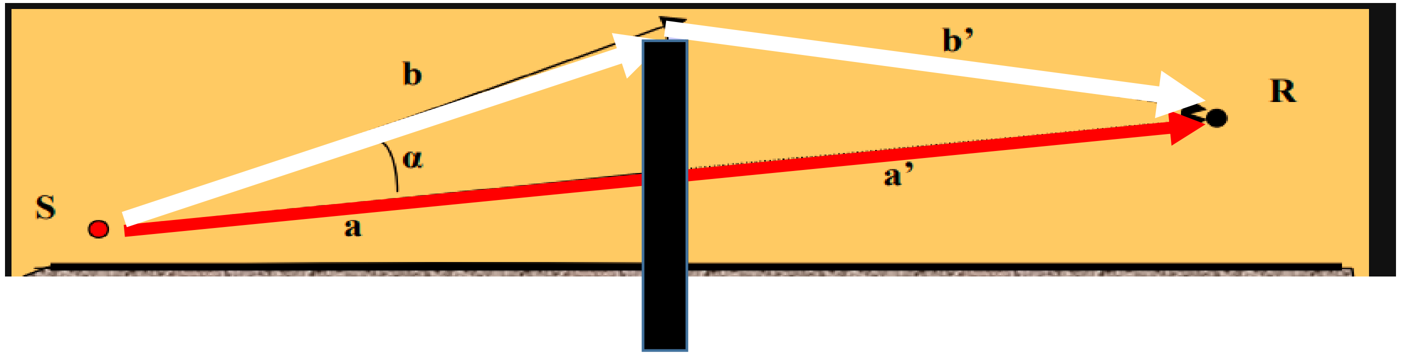
- Today, the use of 3D printers can lead to an appreciable development of the knowledge and practical applications of metamaterials, as complex geometries can be realized according to the objectives you want to achieve.
- With the change of the geometry and with the variation of the volumes of the objects it is possible to obtain a sound attenuation in the desired frequency range, a condition which often cannot be reached with traditional sound-absorbing materials.
- The use of 3D printers makes possible structures that are also aesthetically pleasing and complex, so that the materials can be used as design objects.
- Some authors, using the 3D printer, have created objects with a circular section in which the sound enters and leaves the same point, generating a negative interference between the sound wave at the input and the output ones, which in fact cancels both sound events.


e
(a)
(b)
(c)


(a)
(b)
Ø = 50 mm
w_s = 15 mm
h = 100 mm

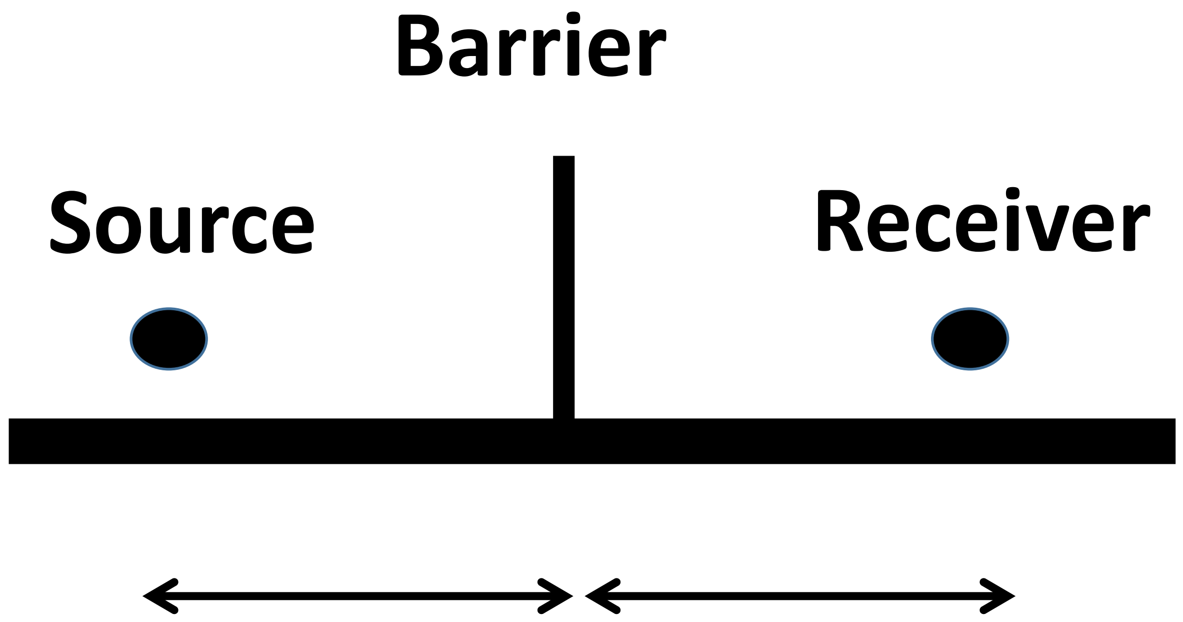
Noise Barrier Acoustic Measurements

Applications such as acoustic barriers limiting traffic noise

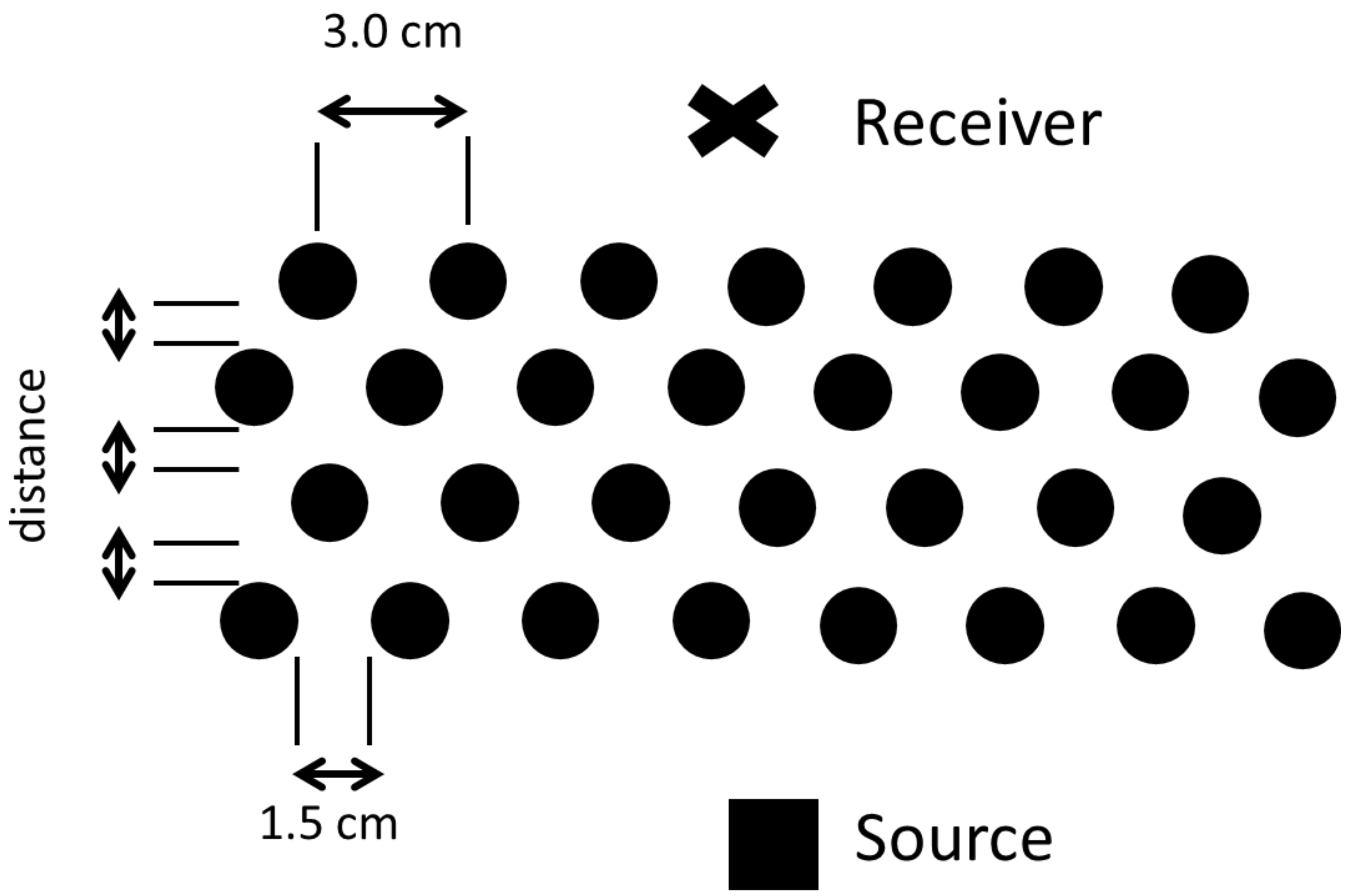


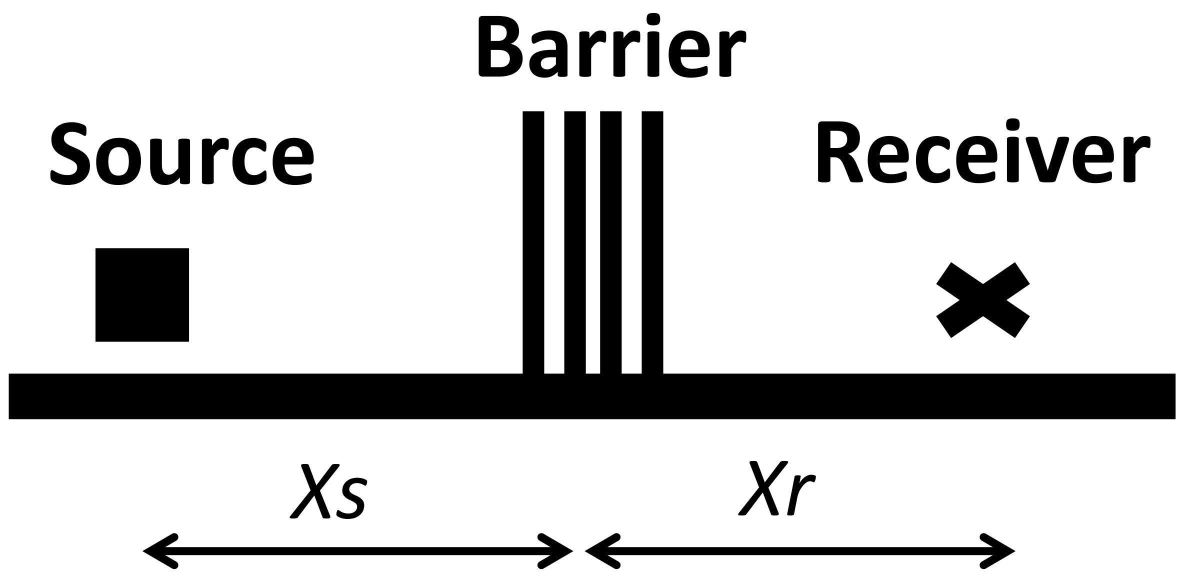
Noise Barrier Acoustic Measurements

- In this paper a study of the attenuation of noise barrier built with metamaterials structures is presented. The noise barrier has a simple geometry, so it is easy to build.
- Furthermore there are known sound attenuation mechanisms.
- The barrier model was built on a scale of 1 to 10 compared to the real dimensions.
- The frequency range of the 1/3-octave bands from 1kHz to 10 kHz (100 Hz to 1000 Hz at full scale) was used.
- The barrier model was built using cylindrical wooden bars 30 cm high and 1.5 cm in diameter.
- The overall geometry of the barrier is made with four rows of cylindrical rods alternating with each other, spacing each row with an empty space equal to the size of the diameter of the sticks, thus creating a regular, empty-full geometry, typical of a structure made with metamaterials.
- The material chosen for the construction of the system is wood as it is an eco-compatible material (which can be disposed of without damaging the environment.

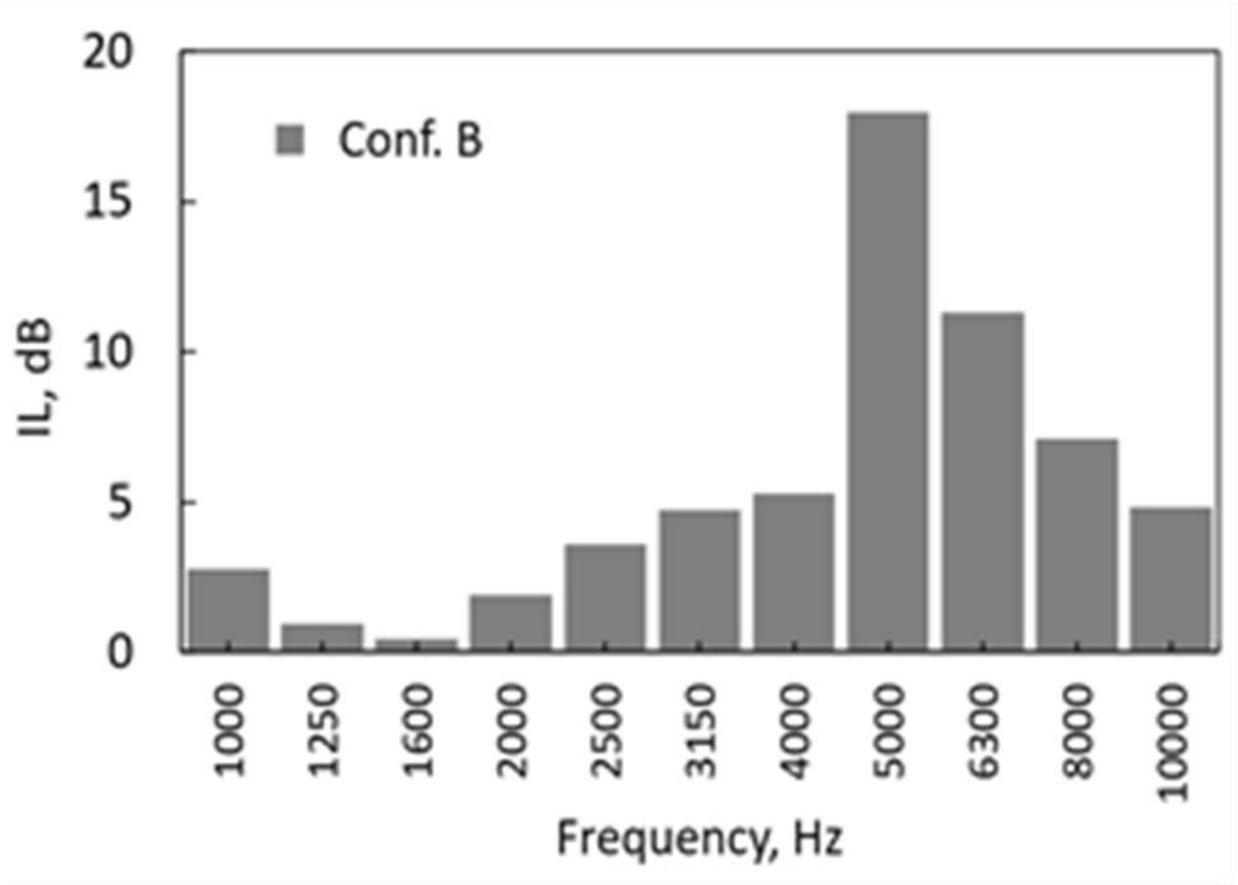

Barrier
Source
Receiver

An omnidirectional spherical sound source was used, small in size compared to those of the barrier, and was placed on one side of the barrier, while a measurement microphone was placed on the opposite side.



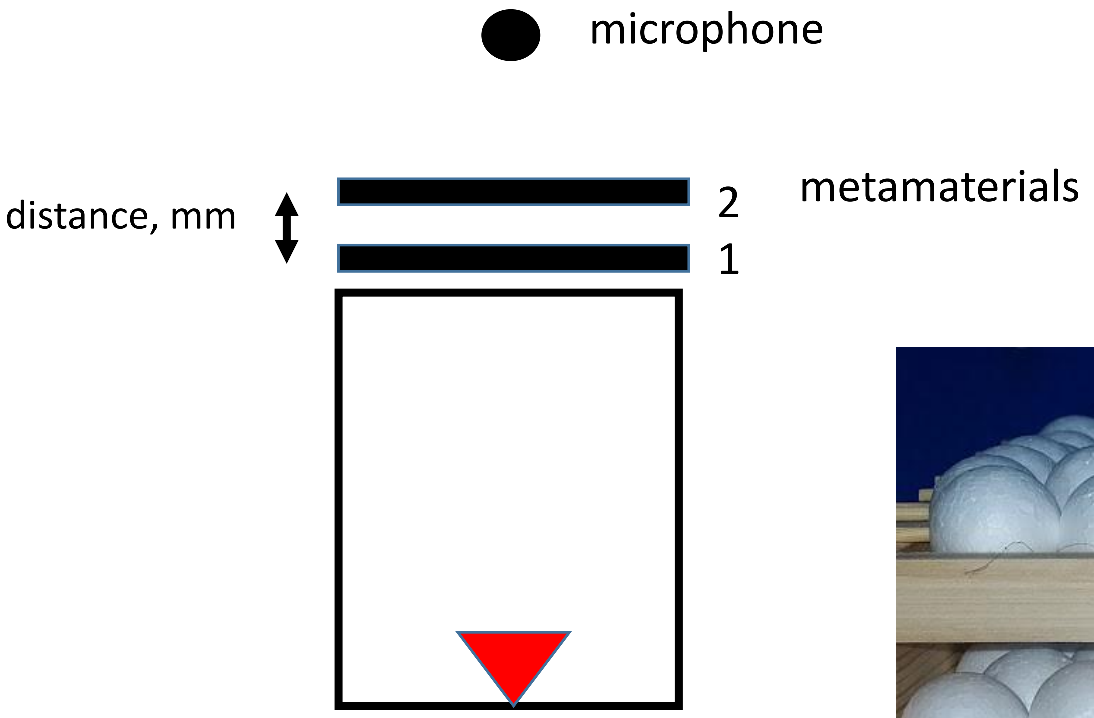


Barrier
Source
Receiver
Xs
Xr



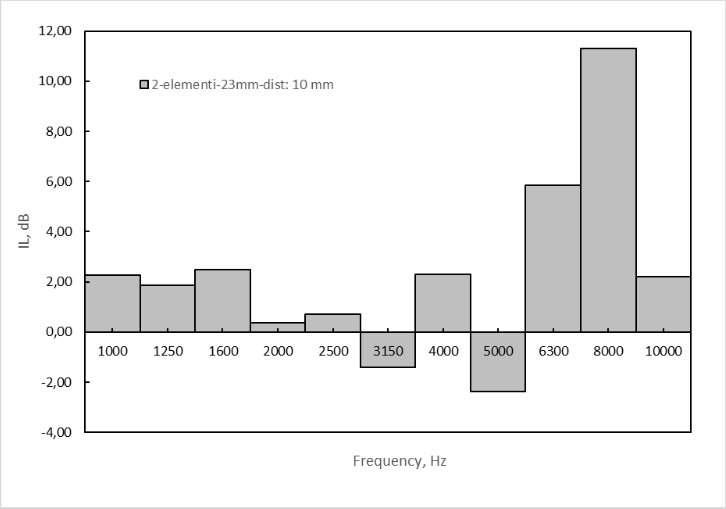
- The results are presented in terms of insertion loss (IL, dB) or as the difference between the sound level measured in the presence of the barrier compared to when it is absent.
- The material chosen to create the system is wood as it is an eco-friendly material.

elements - ball diameter 24 mm

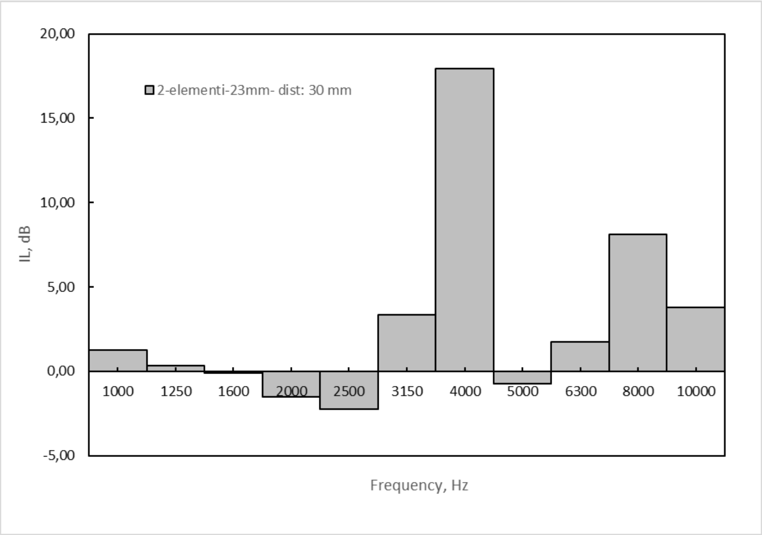


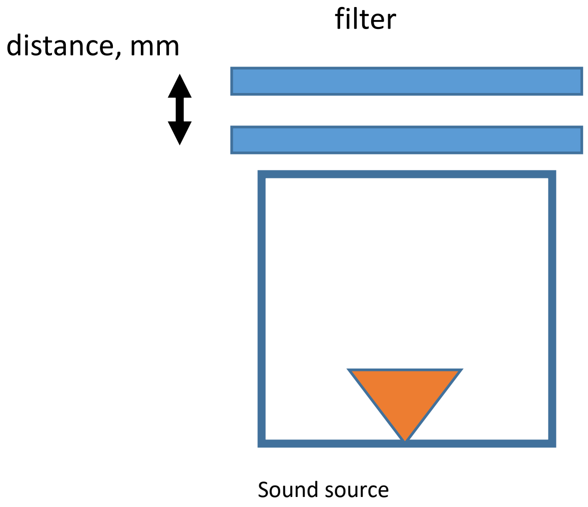
Two elements - ball diameter 24 mm

distance, 10 mm

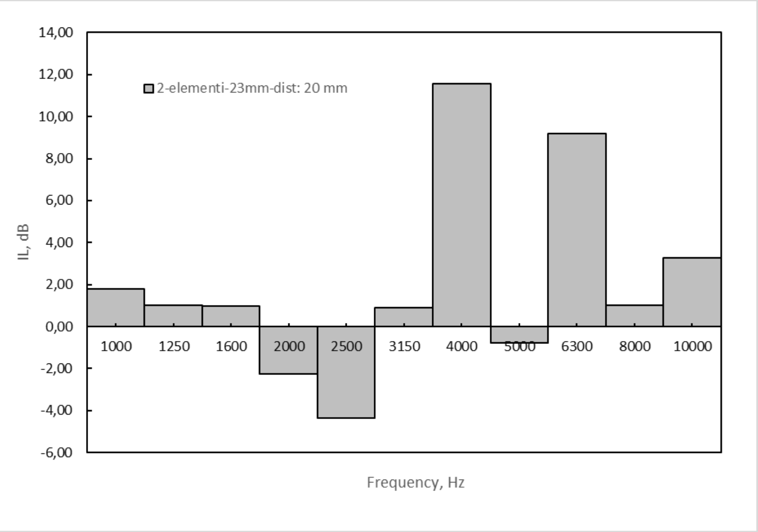


distance, 30 mm

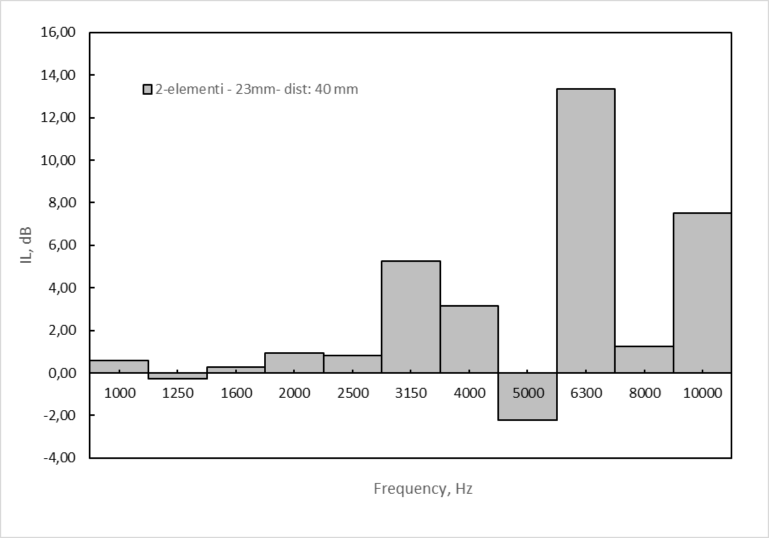


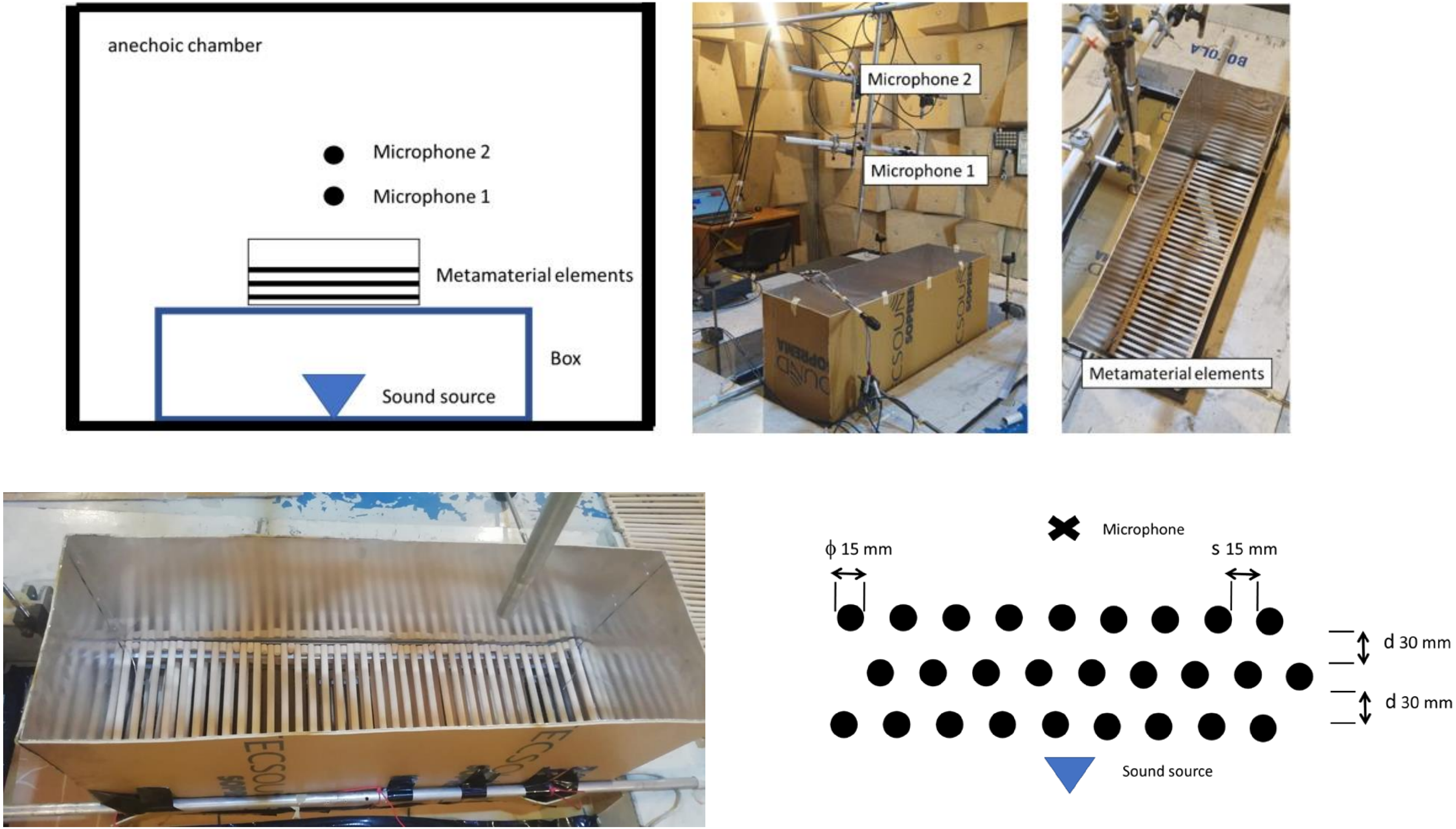


distance, 20 mm

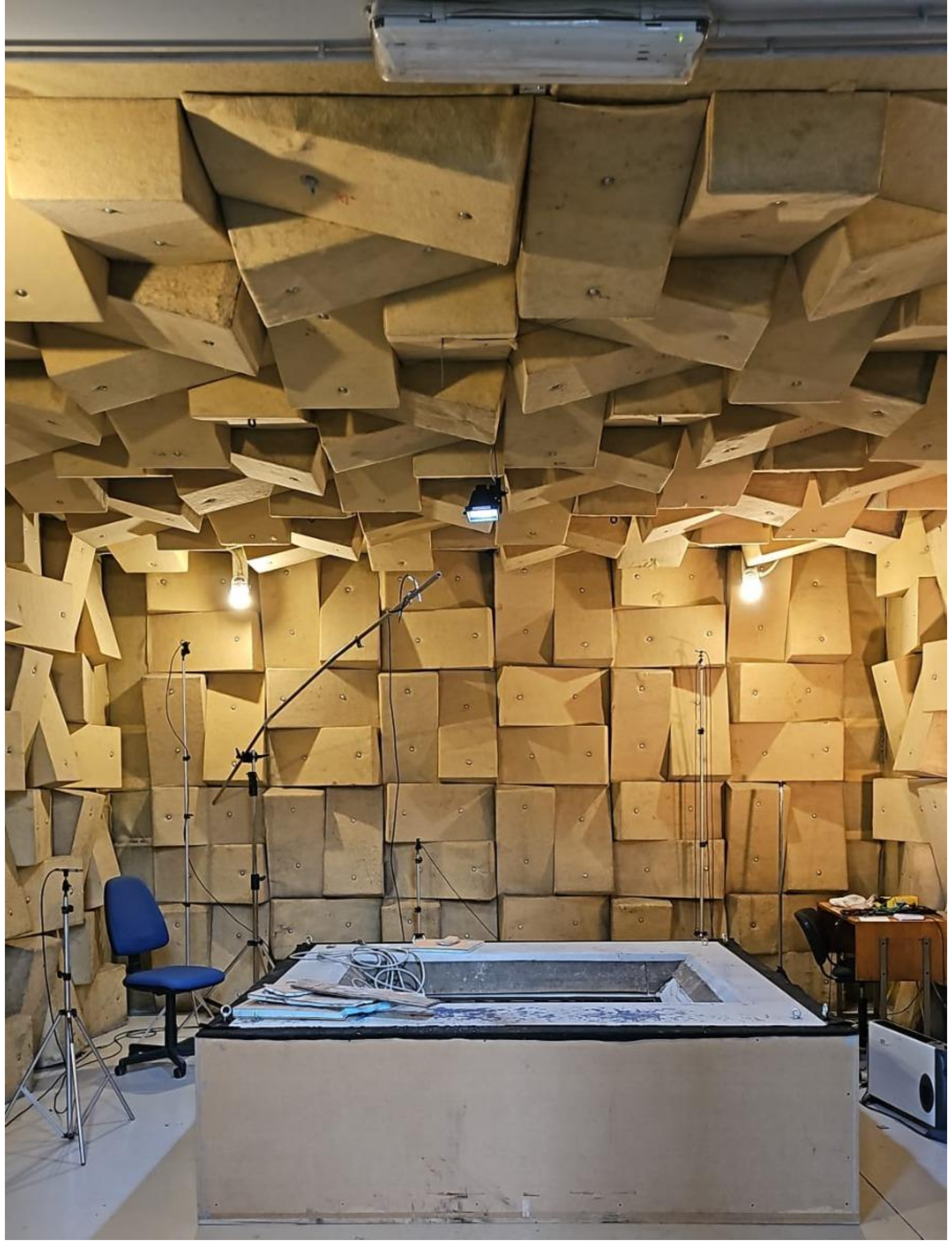


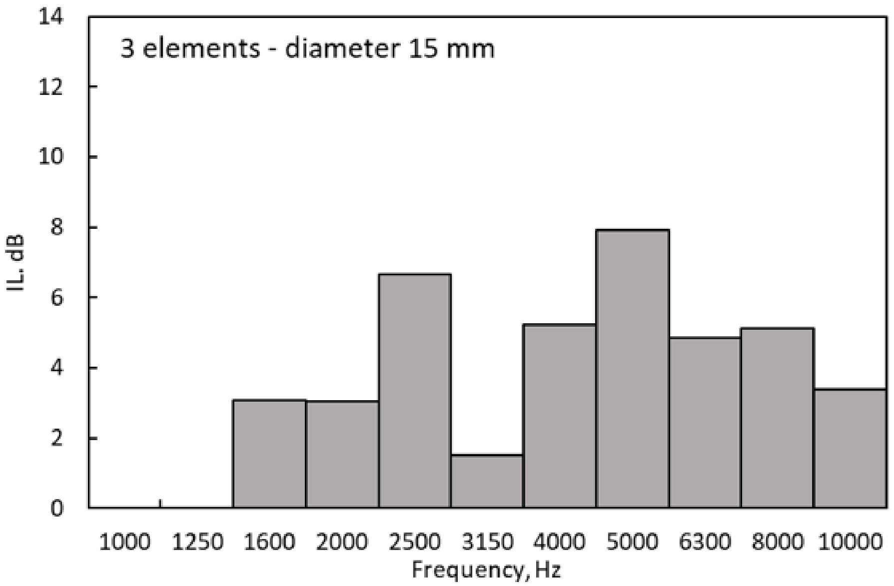
distance, 40 mm

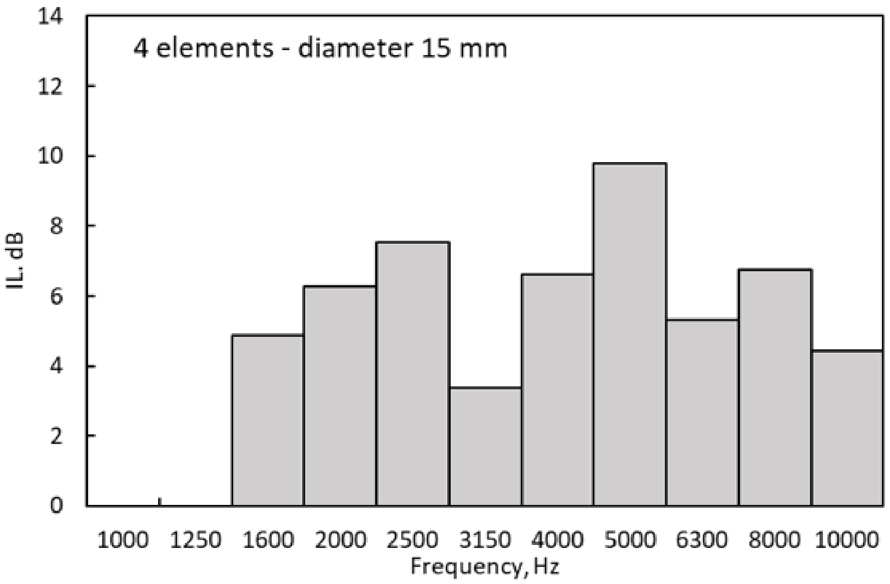




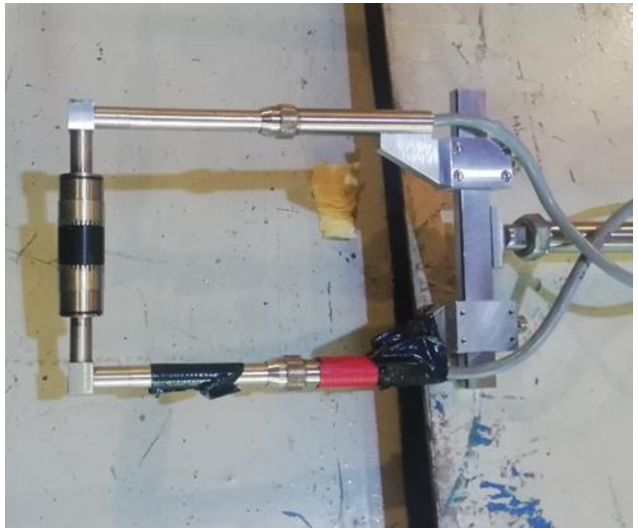
anechoic chamber
Microphone 2
Microphone 1
Metamaterial elements
Box
Sound source
Microphone 2
Microphone 1
Metamaterial elements
Microphone
ϕ 15 mm
s 15 mm
d 30 mm
d 30 mm
Sound source





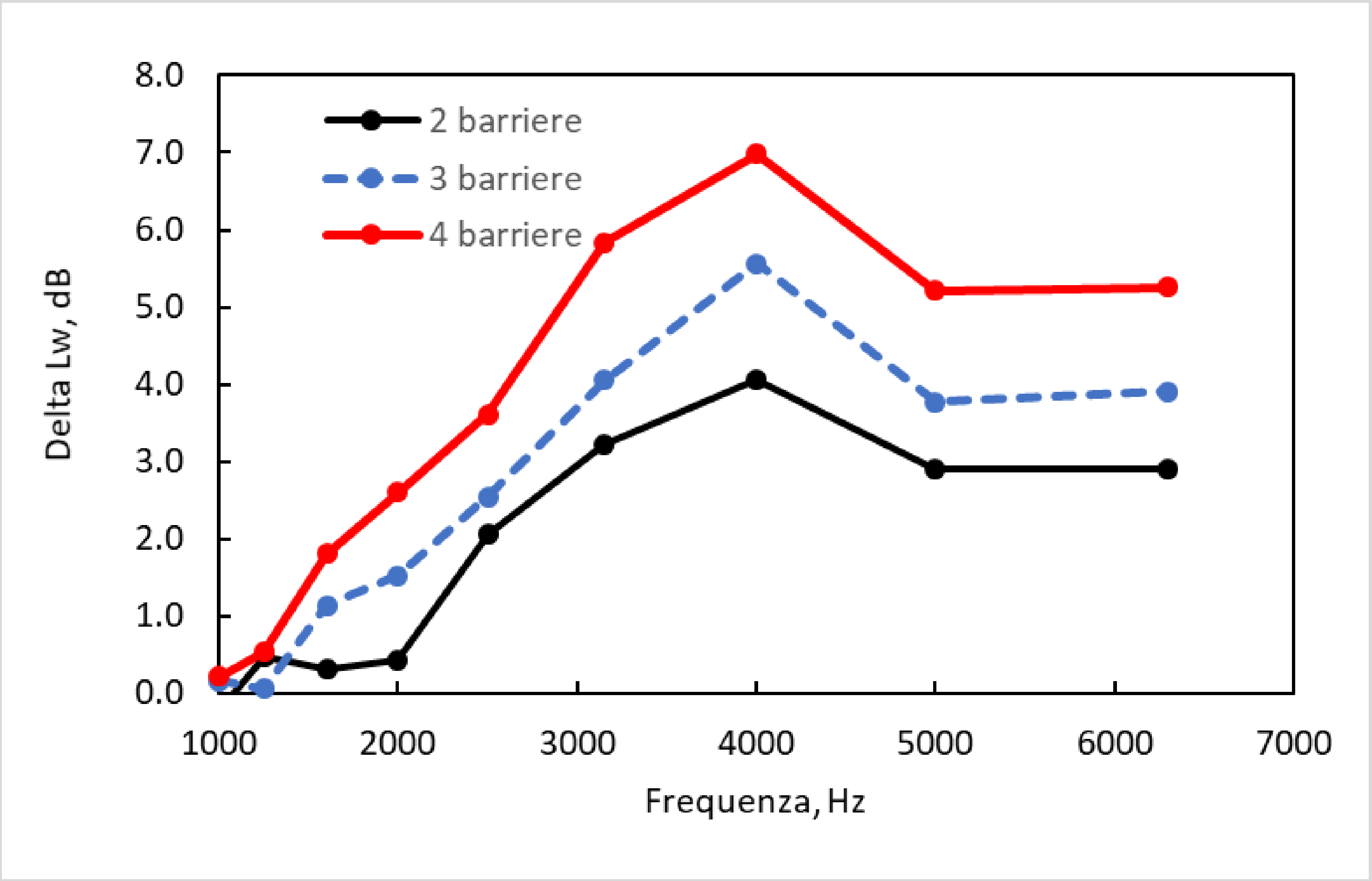


- Figures shows the IL results gathered from the acoustic measurements. Among the variety of outcomes, the focus has been placed onto the values obtained with 3 and 4 rows, always spaced at 30 mm distance
- The diagrams indicate a good sound attenuation in the frequency range comprised between 1.6 kHz and 10 kHz. With 4 rows of scatterers, the sound attenuation increases in the octave of 5 kHz.



Sound intensity measurements – first results

The graph shows the difference between free Lfree(i) – Lbarr(i)
The level of the Li in free field minus the level measured with the barriers.
As expected we see a peak attenuation at 4 kHz



Conclusions

- The results of the acoustic measurements show that the metamaterial structures made with scatterers produce an adequate sound attenuation.
- A potential development of this experimentation is related to the acoustic filters to be placed inside duct lines or to the mechanical units other than related to the elaboration of acoustic barriers for vehicular road traffic noise attenuation.