

## HOT TOPIC 5: Acoustic Metamaterials

How to model and realise a metamaterial for sound absorption in a given frequency range

**Organizers:** Massimo Garai and Gioia Fusaro, University of Bologna

**International UKAN co-organizer:** Tim Starkey, University of Exeter

**Chairs of FA 2023 AMMs session:** Jean Philippe Groby, University of Le Mans; Marco Miniaci, CNRS – France; Massimo Garai, University of Bologna

**Industrial Partners:** Phononic Vibes (Milan) and Multiwave (Swiss)

### ABSTRACT

The participants, organized in small working groups, each helped by an expert instructor, will work on a multiphysics model of a metamaterial for sound absorption. Each group will select a specific model among those proposed in the introductory lecture and try to obtain the maximum absorption in a given frequency range. The best model will be realized by additive manufacturing and tested in an impedance tube. Finally, the participants and the instructors will compare the expected and measured performance and discuss the pros and cons of the different models. A multiphysics program with a temporary licence will be available for each participant.

### TRAINING FLOW

Form: WORKSHOP

1. **Fri 08/09/23 15:30-16:00:** Presentation of the Summer School and the instructor team – Presentation of the "participants' competition" (**GENERAL**) – M. Garai, T. Starkey, G. Fusaro, F. Bosia, T. Cavalieri, L. D'Alessandro, J.P. Groby, N. Jimenez, M. Miniaci, V. Romero-Garcia., B. Ungureanu.
2. **Fri 08/09/23 16:00-17:30:** AMMs mechanisms for sound absorption (**THEORY**), including presentation of the 3 AMMs models selected for the workshop – V. Romero-Garcia
3. **Fri 08/09/23 17:30-18:00:** AMMs applications in the Engineering fields (**CASE STUDIES**) - Phononic Vibes and Multiwave
4. **Sat 09/09/23 10:30-11:30:** Building an AMM model from scratch using COMSOL, considering viscous losses (**THEORY/PRACTICAL**) – N. Jimenez
5. **Sat 09/09/23 11:30-12:00:** Working group formation (students will form WGs of 3-4 persons and choose one of the 3 AMMs models to tune for the competition) (**PRACTICAL**) – each group helped by an expert instructor
6. **LUNCH**
7. **Sat 09/09/23 13:30-15:00:** Parametric optimization of selected AMMs models by participants using COMSOL (**PRACTICAL**) – each group helped by an expert instructor

8. **Sat 09/09/23 15:00-15:10:** Introduction to the YRAM network and activities – [T. Cavalieri](#)
9. **BREAK**
10. **Sat 09/09/23 15:30-17:00:** Parametric optimization of selected AMMs models by participants using COMSOL (**PRACTICAL**) – [each group helped by an expert instructor](#)
11. **Sat 09/09/23 17:00-17:30:** Discussion on the numerical approach issues and overall Q&A + Selection of the best AMMs model developed by participants (**PRACTICAL**) – [by expert instructors](#)
12. **3D PRINTING DURING THE NIGHT (PoliTO or Phononic Vibes)** (4/5 samples to be printed beforehand as a backup plan)
13. **Sun 10/09/23 08:30-10:00** Impedance tube measurements of the best AMMs model + discussion (**PRACTICAL**) – PoliTO ([L. Shtrepi](#))
14. **BREAK**
15. **Sun 10/09/23 10:30-12:00** Comparison of expected and measured performance of the selected AMM, pros and cons, discussion with participants (**THEORY +PRACTICAL**) – [Instructor team](#)

[At the end of the workshop, the participants will be able to manage the industrial prototyping of an AMMs-based engineered system, starting from the physical principles, using a multiphysics-based parametric optimization and finally discussing pros and cons \(supported by both physical reasons and industrial application\)](#)

(A specific Calendar with the exact time slots will be provided by the Summer School organizers once all the Hot Topic forms will be collected)

#### KEY TRAINERS (in alphabetical order)

- Prof. Federico Bosia (Polytechnic University Turin) [federico.bosia@polito.it](mailto:federico.bosia@polito.it)

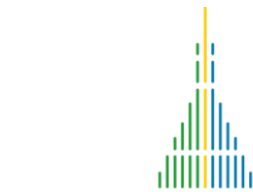


Federico Bosia graduated in Physics at the University of Torino and obtained a PhD in Mechanical engineering in 2002 at EPFL (Switzerland). He is currently an associate professor at Politecnico di Torino. He has published about 120 papers in leading international journals. He is currently involved in a FET Open project "Boheme" on Bioinspired hierarchical metamaterials and two metamaterials-related FET Launchpad projects "Silence" and "Biometarail".

- Dr. Théo Cavalieri (EMPA) [theo.cavalieri@empa.ch](mailto:theo.cavalieri@empa.ch)



Dr. Théo Cavalieri is currently a post-doctoral researcher and the co-chair of YRAM Network (Young Researchers in Acoustic Metamaterials). Through his Master studies, his PhD, and his first post-doc at LAUM-CNRS, France, he has collaborated with three international actors of the transport industry, and developed acoustic solutions for airborne sound: from resonant phononic crystals, to 3D printed metamaterials and more recently acoustic meta-lenses for directivity control. Dr. Cavalieri is now conducting his second postdoc on low-frequency sound absorbers made of mineral foams for the Acoustic/Noise Control lab at Empa (Swiss Federal Laboratories for Materials Science and Research), in Zürich area, Switzerland.



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- Dr. Luca D'Alessandro (Phononic Vibes)

[luca.dalessandro@phononicvibes.com](mailto:luca.dalessandro@phononicvibes.com)



Luca D'Alessandro is co-founder and CEO of the industrial partner Phononic Vibes Srl (Politecnico di Milano Spin-Off). D'Alessandro had his PhD at Politecnico di Milano in Seismic, Environmental and Structural Engineering with a visiting period at MIT Cambridge, MA (US). His research focus was on algorithms and methodologies for Phononic Crystals and Elastic Metamaterials design and optimization with a focus on ultra-wide bandgap for vibration and noise attenuation.

- Dr. Gioia Fusaro (University of Bologna) [gioia.fusaro@unibo.it](mailto:gioia.fusaro@unibo.it)



Gioia Fusaro is a Postdoctoral Research Fellow at the University of Bologna, Industrial Engineering Department, Applied Physics Research Group. She is a Fellow of Higher Education Academy (UK), and a chartered Architect, Building Engineer, and Acoustician (IT). Her main interests in research are building and environmental acoustics, materials and metamaterials, environmental sustainability, soundscape, psychoacoustics, ergonomics, industrial design, and social sciences.

- Prof. Massimo Garai (University of Bologna) [massimo.garai@unibo.it](mailto:massimo.garai@unibo.it)



Full Professor at the University of Bologna since 2001. Main research topics: digital signal processing, new materials and metamaterials, acoustic simulation, the acoustics of historical Italian opera houses, noise control outdoors, and environmental sustainability. Authored more than 300 papers. Coauthored four specialized books on applied acoustics. Working on several national and international research projects, cooperating with European research centres. President of the "Acoustics and Vibrations" commission of UNI since 2013 and convenor of CEN/TC256/SC1/WG40 and CEN/TC226/WG6/TG1. Received some "best paper" awards in international congresses and some "outstanding reviewer" awards from Elsevier. Awarded by UNI with the Paolo Scolari Prize 2022.



- Prof. Jean-Philippe Groby (CNRS - LAUM) [Jean-Philippe.Groby@univ-lemans.fr](mailto:Jean-Philippe.Groby@univ-lemans.fr)



Jean-Philippe Groby is CNRS researcher at the Acoustics Laboratory of Le Mans University since 2009. He holds an Engineering degree from École Centrale de Marseille (École Supérieure d'Ingénieurs de Marseille), a M.Sc. in Acoustics, and a Ph.D. in Mechanical Engineering (2005) from the University of the Mediterranean Aix-Marseille II. He has been a post-doctoral fellow in KULeuven, École Polytechnique (CMAP, UMR CNRS 7641), Supélec (L2S, UMR CNRS 8506), and IEMN (UMR CNRS 8520). His research focuses on acoustic waves in complex and structured media, as well as in metamaterials. He has been actively involved in the professional life of the acoustic community in Europe, notably serving as a chair of the COST Action DENORMS CA 15125. He is currently chair of the EAA Technical Committee on Acoustic Materials.

- Dr. Noé Jiménez (i3M/Spanish Research Council (CSIC)) [nojigon@upv.es](mailto:nojigon@upv.es)

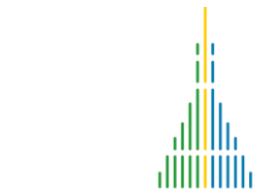


Noé Jiménez is Postdoctoral Research Fellow at the Universitat Politècnica de València at Instituto de Instrumentación para Imagen Molecular. He was a research fellow at CNRS (France), Salford University (UK), and Columbia University (NY, USA). His main research interests are wave propagation in complex, structured and metamaterials and its use to develop novel architectural, industrial and biomedical applications.

- Dr. Marco Miniaci (University of Lille) [marco.miniaci@univ-lille.fr](mailto:marco.miniaci@univ-lille.fr)



Researcher at the French National Scientific Research Centre (CNRS) and chartered Civil and Environmental Engineer. Marco Miniaci is specialized in wave dynamics, periodic structures, and metamaterials that he investigates through numerical modelling and experimental measurements (in the sonic and ultrasonic regime). Recently Marco Miniaci has been granted the ERC StG project "POSEIDON" dealing with metamaterials for underwater acoustics.



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- Dr. Vicente Romero-Garcia (Universitat Politècnica de València) [virogar1@mat.upv.es](mailto:virogar1@mat.upv.es)



Vicente Romero-García is a lecturer at the Applied Mathematics Department of the Polytechnic University of València. His research activities are related to wave physics and, in particular, to complex media such as metamaterials, hyperuniform structures and crystals. He has published highly cited works on these long-standing topics and participated in as invited in various conferences. I have co-directed several doctoral and post-doctoral researchers through several competitive projects and research contracts.

- Dr. Tim Starkey (Exeter/UKAN AMMs) [t.a.starkey@exeter.ac.uk](mailto:t.a.starkey@exeter.ac.uk)



Tim is a Senior Research Fellow in the Centre for Metamaterial Research and Innovation at the University of Exeter. His research involves experimental, numerical and analytical research methodologies to develop the science and technology underpinning the next generation of acoustic and elastic metamaterials.

- Dr. Bogdan Ungureanu (Le Mans, Imperial College, MetaMAT) [b.ungureanu@imperial.ac.uk](mailto:b.ungureanu@imperial.ac.uk)



Bogdan UNGUREANU, PhD. Eng. in Civil Engineering is currently an associate researcher in LAUM, the Acoustic Laboratory of Université du Mans, in France, and a former Marie-Curie Fellow in the Mathematics Department of Imperial College London (ICL), UK. He is a trained civil engineer in Structural Mechanics, specialising in risk assessment in urban infrastructures working on Seismic Metamaterials and metamaterials to control deleterious vibrations. Graduated from the Gheorghe Asachi Polytechnic University of Iasi in Romania, he has performed part of his PhD thesis in the CNRS physics laboratory Institut Fresnel in France, thereby broadening his area of interest going from Applied Mathematics and Mathematical Physics to Civil Engineering and Risk Management.





## EQUIPMENT

- Individual laptop of each participant
- Matlab installed in participants laptop
- Comsol (Comsol Multiphysics will sponsor temporary license of 14 days from the 6th of September) – Passcode will be shared with the participants on the 6th of September and the software must be installed before the starting of the summer school
- 3D printer (FDM, Dremel Digilab 3D45) and nylon filament (other filaments can be purchased on request), usable during the night 9-10 September 2023 – F. Bosia (Turin)
- 3D printer (FDM, Creality Ender or CB-200) and PLA filament, usable during the night 9-10 September 2023 – Phononic Vibes (Milan)
- Impedance tube cylindrical by SIEMENS (35 mm, 50-5700 Hz) + SIEMENS proprietary software for sound absorption (two mics), usable on 10 September 2023 morning – L. Shtrepi (Turin)

## REQUIREMENTS FOR PARTICIPANTS (to be checked upon inscription)

- Bring their individual laptop (with installed COMSOL with a temporary license which will be shared on the 6<sup>th</sup> of September)
- Have a basic knowledge of Matlab and COMSOL

## ABOUT COMPANIES

- *Phononic Vibes - Phononic Vibes (Politecnico di Milano Spin-off) is a DeepTech company with a focus on noise and vibration management in all aspects of our living, considering both performances and sustainability. Phononic relies its products and solutions on metaMaterial technology thanks to strong competencies in shape and topology optimization with a sharp focus on industrialization and industrial production of new solutions. Within the first 4 years of activity, focus has been given to the industrial feasibility and costification of the original Metastructures from academia and evolving them into industrial products.*

*Phononic raised three financing rounds from Venture Capital Funds [total 8M€ raised] and filed 12 Patents since the incorporation in 2017. The key sectors and markets are Infrastructure (railway, tram, acoustic barrier), Transportation (automotive, naval, aviation) and Appliances (Cooker Hood, Vacuum cleaners, Dryers, Heat Pumps).*



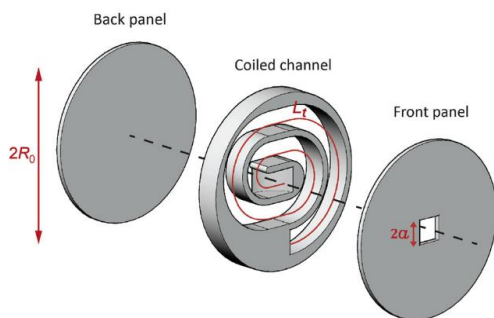
*Phononic's Team is now composed by fourteen people with different background in Engineering, Industrial Design, Business and Marketing sectors.*

- *Multiwave - Multiwave Technologies AG is a deep science technology company headquartered in Geneva, Switzerland. Founded in March 2015, Multiwave identifies market needs across industries and incubates metamaterial technologies to answer these needs with a view to improving living standards. Multiwave is a member of the BOHEME European project for which the company is developing analytical and numerical techniques for the modelling and experimental validation of metamaterials dedicated for specific applications. Multiwave also contributes to the design and optimization of noise-reducing structures and coatings, in particular for MRI devices.*

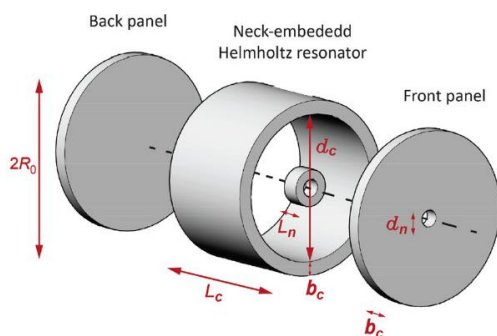
### POTENTIAL AMMs MODELS

Below are listed some potential AMMs structure to be i) included in the preliminary lecture part (schedule points 2-4), ii) numerically modelled by the students (schedule points 5-10), and iii) tested in the impedance tube to compare the expected numerical results with the experimental ones (schedule points 11-15).

- Single coiled-up resonator



- Neck embedded resonator



- o Double coiled up resonator

