Time-varying Acoustic Metamaterials
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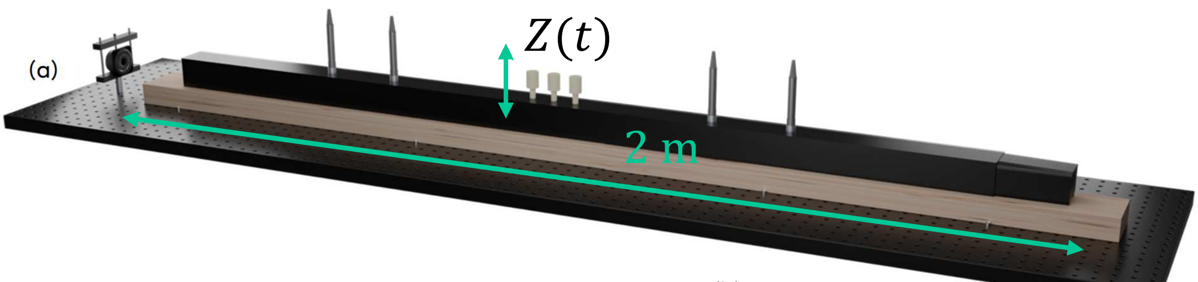
Metamaterial research is commonly concerned with designing sub-wavelength scale structures that exhibit effective material properties due to their engineered variation in space. A new paradigm for wave manipulation and information processing is booming due to the advent of time-varying metamaterials whose properties are modulated in time. New Phenomena has emerged, beyond the limits set by energy conservation and time-reversal symmetry, enabling the control of wave momentum, frequency, and digital information, offering unique applications such as nonreciprocity, smart reconfigurable response, wave synthesis, and next-generation wireless communications, across electromagnetism, acoustics and mechanics [R. Sapienza, et al. APL 123.16 (2023)].

Varying material properties in time can be achieved using resonance: when two wave resonators are coupled, energy is exchanged and the wave eigenmodes are reshaped through strong coupling. If the coupling is dynamic and varies in time, *on time-scales comparable to the coupling rates*, the coupled system can be dramatically transformed: new resonant frequencies are formed, and the gain and loss of the coupled system is modified, both in total value (energy extraction from the coupling modulation) and in distribution between the two resonators [H. Ghaemi-Dizicheh arxiv:2302.00877 (2023)].

Classical, linear acoustics serves as a testbed for the exotic physics permitted by time-varying materials as the modulation timescales can be much faster than the coupling rates due to the (relatively) slow wave speed. This unexplored regime has the potential to allow for very fast modulation of the response of the coupled system and wave control, especially close to exceptional points [B. Longstaff et al. Phys. Rev. A 100, 052119 (2022); R. Melanathuru et al. Phys. Rev. A 10, 012208 (2022)]. In acoustics the overlap of the resonant fields can be modified via the spatial separation of the meta-atoms (e.g., Helmholtz resonators); this coupling shall temporally modulated using control electronics with e.g., Raspberry Pis.

This summer project will comprise a blend of simulation and experimental set-up; we will utilise finite element modelling to analyse acoustic wave propagation down a waveguide with temporally varying properties, provided by modulated coupling of embedded resonators. The simulations will be confirmed with experimental methods performed in an impedance tube, the set-up of which will form a large component of this project and facilitate important future experimental capabilities that shall be leveraged throughout the recently funded Programme Grant 'Meta4D' (https://news.exeter.ac.uk/top-stories/research-to-build-next-generation-of-metamaterials-receives-multi-million-pound-funding-boost/).



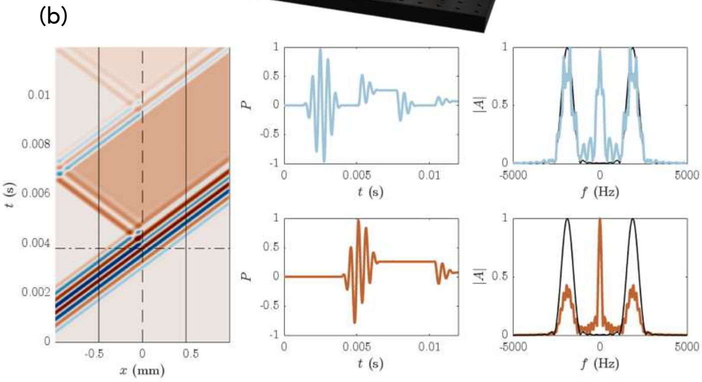


Fig 1. (a) Schematic of experimental set-up. A long, custom, impedance tube is dressed with coupled resonators whose effective impedance *Z(t)* varies temporally. (b) Example reflection and transmission spectra at temporal interfaces that will be measured in the experiments.