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Merging mechanical and electromechanical bandgaps in locally resonant metamaterials and metastructures

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Abstract

Locally resonant metamaterials are characterized by bandgaps at wavelengths much larger than the lattice size. Such locally resonant bandgaps can be formed using mechanical or electromechanical resonators. However, the nature of bandgap formation in mechanical and electromechanical (particularly piezoelectric) metamaterials is fundamentally different since the former is associated with a dynamic modal mass, while the latter is due to a dynamic modal stiffness. Next-generation metamaterials and resulting metastructures (i.e. finite configurations with specified boundary conditions) hosting mechanical resonators as well as piezoelectric interfaces connected to resonating circuits can enable the formation of two bandgaps, right above and below the design frequency of the mechanical and electrical resonators, respectively, yielding a wider bandgap and enhanced design flexibility as compared to using a purely mechanical, or a purely electromechanical configuration. In this work, we establish a fully coupled framework for hybrid mechanical-electromechanical metamaterials and finite metastructures. Combined bandgap size is approximated in closed form as a function of the added mass ratio of the resonators and the system-level electromechanical coupling for the infinite resonators approximation. Case studies are presented for a hybrid metamaterial cantilever under bending vibration to understand the interaction of these two locally resonant metamaterial domains in bandgap formation. Specifically, it is shown that the mechanical and electromechanical bandgaps do not fully merge for a finite number of resonators in an undamped setting. However, the presence of even light damping in the resonators suppresses the intermediate resonances emerging within the combined bandgap, enabling seamless merging of the two bandgaps in real-world structures that have damping. The overall concept of combining mechanical and electromechanical bandgaps in the same single metastructure can be leveraged in more complex topologies of piezoelectric metamaterial-based solids and structures.

Keywords: Metamaterial, metastructure, locally resonant, bandgap, hybrid.

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