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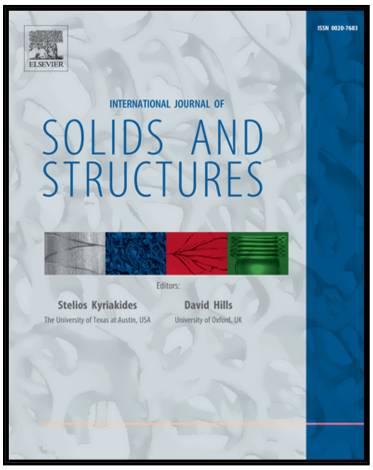


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# Multi-parametric sensitivity analysis of the band structure for tetrachiral acoustic metamaterials

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**Abstract**

Tetrachiral materials are characterized by a cellular microstructure made by a periodic pattern of stiff rings and flexible ligaments. Their mechanical behaviour can be described by a planar lattice of rigid massive bodies and elastic massless beams. The periodic cell dynamics is governed by a monoatomic structural model, conveniently reduced to the only active degrees-of-freedom. The paper presents an explicit parametric description of the band structure governing the free propagation of elastic waves. By virtue of multiparametric perturbation techniques, sensitivity analyses are performed to achieve analytical asymptotic approximation of the dispersion functions. The parametric conditions for the existence of full band gaps in the low-frequency range are established. Furthermore, the band gap amplitude is analytically assessed in the admissible parameter range. In tetrachiral acoustic metamaterials, stop bands can be opened by the introduction of intra-ring resonators. Perturbation methods can efficiently deal with the consequent enlargement of the mechanical parameter space. Indeed high-accuracy parametric approximations are achieved for the band structure, enriched by the new optical branches related to the resonator frequencies. In particular, target stop bands in the metamaterial spectrum are analytically designed through the asymptotic solution of inverse spectral problems.

*Keywords:* Periodic materials, Acoustic metamaterials, Wave propagation, Perturbation methods, Sensitivity analysis

## 1. Introduction

Several theoretical and applied research fields are currently developing a renewed interest in the high mechanical performances of cellular and periodic materials. Consequently, their traditional role of efficient structural elements is undergoing a rapid evolution. This trend is also catalyzed by virtuous synergies with the recent extraordinary developments in parametric design, multi-scale modeling, computational techniques and multi-disciplinary meta-analyses. Within this scientific framework, advanced theoretical formulations and revolutionary manufacturing technologies contribute to offer solid prospects for the birth of new-generation materials, with superior mechanical properties and smart multi-field functionalities.

Within the specific context of solid and structural mechanics, a promising challenge focuses on exploiting the periodic microstructure and the marked anisotropy of some chiral or anti-chiral lattice materials to steer or stop elastic waves along particular directions. One of the simplest planar configuration realizing a chiral honeycomb consists of a regular microstructure made of stiff disks or rings, connected by a variable number of flexible ligaments [1–3]. The leading idea is that, within certain admissible ranges, the microstructural parameters can be employed as design variables to tailor the dispersion properties of the material. Among the possible technological advances, an appealing goal is the synthesis of highly-costumizable elastic media, suited to serve as mechanical guides or phononic filters for optical and acoustic signals.

Based on these motivations, considerable research attention has been devoted over the last decade to analyze and/or control the dispersion properties of different periodic microstructures with chiral characteristics. These analyses have been based on low-dimensional Lagrangian models [4–6], high-fidelity computational formulations [7–9], equivalent homogenized continua [10–14] and experimental prototypes [15]. A decisive boost to the research on this topic comes from the discovery that stop bands can be opened in the spectrum of a chiral solid through the introduction of local resonators. In periodic materials with chiral ring-ligament microstructures, local resonators can be realized by intra-ring masses elastically connected with the hosting rings. The microstructured material enriched with these auxiliary masses (inertial resonators) can be classified as an elastic or acoustic metamaterial (inertial metamaterial). Acoustic metamaterials have already attracted several studies focused on both direct and inverse spectral problems [16–19].

According to the simplest mathematical formulation, the *direct* spectral problem consists in determining the dispersion function $\omega(\mathbf{p}, \mathbf{k})$ in the Brillouin domain $\mathcal{B}$, spanned by the wavevector $\mathbf{k}$, for a certain periodic material, fully described by a given set $\mathbf{p}$ of microstructural parameters. The spectral design, instead, can be regarded as an *inverse* problem, consisting in determining which parameter set $\mathbf{p}$ realizes an unknown periodic material (if one exists), characterized by a desired dispersion function $\omega(\mathbf{p}, \mathbf{k})$. Clearly, the solution of any direct or inverse spectral problem can greatly benefit from the availabil-

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