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Nonlinear Hierarchical Cells for Passive Amplitude Filtering

Abstract

We present two nonlinear hierarchical unit cell designs for passive, amplitude filtering of acoustic energy transmission analogous to frequency filters. The hierarchical cells consist of an inner mass nonlinearly coupled to an outer mass. The two cells are differentiated by their linear and nonlinear stiffness coupling within the cell and to neighboring cells of attached linear waveguides. The first nonlinear unit cell acts as a high-amplitude filter transmitting signals above a sufficient amplitude, while the second design acts as a low-amplitude filter transmitting signals below a threshold amplitude. Importantly, both filters act with little signal distortion. We first present numerical simulations and analytical models revealing the operation of the unit cells at varying frequencies and amplitudes. These studies reveal that the high-amplitude filter reflects energy at small amplitudes, while locking of the inner mass to the outer mass leads to perfect transmission at higher amplitudes. The low-amplitude filter exhibits a drop in transmission due to the inner mass of the hierarchical unit cell acting as a nonlinear energy sink at large amplitudes. The numerical and analytical results are verified by a series of experiments using fabricated nonlinear unit cell designs. We construct the linear waveguides using steel masses and 3D-printed serpentine springs, while the nonlinear unit cells utilize a self-contacting nonlinear serpentine spring. We document amplitude filtering over a broad frequency range which agree strongly with the numerical and analytical predictions. The ability to passively filter signals based on amplitude, in isolation or combined with frequency filters, may find application in reduction of noise in communication devices, isolation of sensitive components, and other tasks in acoustic signal processing.

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