Digitally programmable piezoelectric metamaterials and nonlinear electromechanical structures with synthetic impedance circuits

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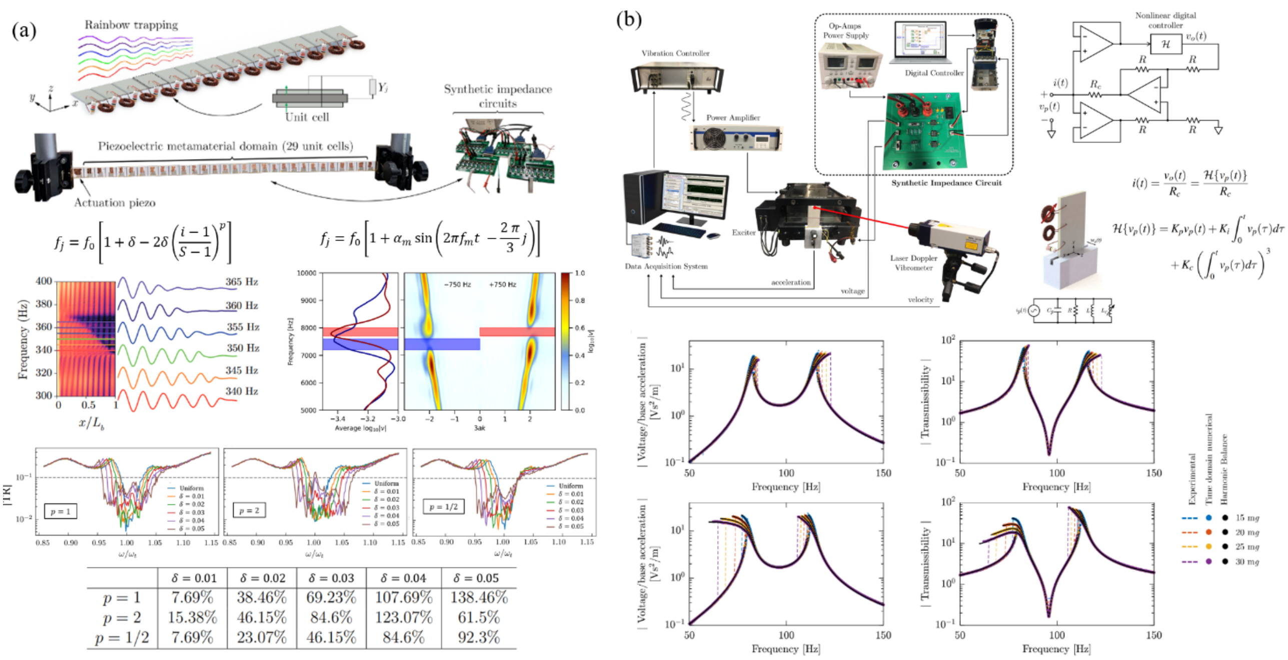
Abstract. We summarize our efforts on using synthetic impedance circuits in two domains: digitally programmable (1) piezoelectric metamaterials with spatially and spatiotemporally varying properties, and (2) nonlinear piezoelectric structures enabled through Duffing-type shunts. In the first domain, we demonstrate the capabilities in this new class of metamaterials using spatially varying inductive shunts for rainbow trapping and spatiotemporal modulation of inductive shunts for reciprocity breaking, via experiments and numerical simulations. In the second part, we extend the synthetic impedance shunts to nonlinear Duffing type hardening/softening inductance and present experimental results and harmonic balance simulations to show exceptional tunability from hardening to softening Duffing dynamics with the same single structure.

Introduction

Tunability and reprogramming are not straightforward in typical mechanical (elastic/acoustic) metamaterials and metastructures. We explore possibilities to this end using synthetic impedance shunts. In another research domain, it is well known that nonlinearities can be exploited in vibration attenuation and isolation. Researchers have recently explored nonlinear mechanical attachments in metastructures [1,2]. Here, we explore synthetic impedance circuits for piezoelectric structures to enable nonlinear attachments that are digitally programmable.



	$\delta = 0.01$	$\delta = 0.02$	$\delta = 0.03$	$\delta = 0.04$	$\delta = 0.05$
$p = 1$	7.69%	38.46%	69.23%	107.69%	138.46%
$p = 2$	15.38%	46.15%	84.6%	123.07%	61.5%
$p = 1/2$	7.69%	23.07%	46.15%	84.6%	92.3%

Figure 1: Synthetic impedance-based programmable piezoelectric metamaterials and nonlinear electromechanical structures: (a) Examples of rainbow trapping and nonreciprocal wave propagation by spatially and spatiotemporally programming the inductive shunts, along with results of bandgap enhancement in the rainbow case. (b) Duffing-type hardening and softening inductive synthetic shunt circuit connected to a cantilevered piezoelectric structure under base excitation.

Results

Through digital programming of inductive shunts, we have demonstrated concepts spanning from the rainbow trapping phenomenon and bandgap enhancement by means of that (via various profiles of inductive shunt frequencies from fractional to quadratic) [3] to tunable nonreciprocal wave propagation (Fig. 1a). We have also established Duffing type digitally-controlled nonlinear shunts [4] to implement (Fig. 1b) in metastructures.

References

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[3] Alshaqaq, M., Sugino, C., and Erturk, A., 2022, “Programmable Rainbow Trapping and Bandgap Enhancement via Spatial Group Velocity Tailoring in Elastic Metamaterials,” *Physical Review Applied*, **17**, L021003.

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