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Solidifying Transmission Reduction of Piezoelectric Metamaterial Beam through Synthetic Impedance Circuits with Parasitic Resistance Compensation

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Abstract—The piezoelectric metamaterials, typically consisting of identical piezoelectric transducers shunted with local resonant circuits, are conceptually appealing for wave attenuation and vibration isolation. Nevertheless, significant barriers exist. The bandgap widths are generally narrow, and the transmission reduction is limited when the number of unit cells is relatively small in practical situations. In particular, most existing investigations focus on the theoretical aspects, and the mechatronic synthesis for validation and implementation is lacking. This research aims at addressing the fundamental challenges in realizing wide-band transmission reduction of piezoelectric metamaterial beams by means of a comprehensive circuitry integration. We first formulate an analytical transmittance analysis in the wave domain which is utilized to elucidate the parametric influence of circuitry integration. We then carry out a systematic experiment-based investigation of the enhanced piezoelectric metamaterial featuring the integration of a tunable synthetic inductance and negative capacitance, in order to achieve improved transmission reduction over a broadened bandgap frequency range. While the negative capacitance is theoretically helpful, it is illustrated that the parasitic resistance will negate its benefit. It is then demonstrated that the subsequent introduction of the negative resistance within the same synthetic impedance circuit can significantly enhance the system performance. This research provides critical insights into the implementation of piezoelectric metamaterials using synthetic impedance circuit integration, which lays the foundation for system-level application of such concepts for wave attenuation and vibration isolation.

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