Multi-Frequency Optimization of Acoustic Metasurface-Based Sound Energy Harvesting

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Everyday environmental noise consists of multiple mixed frequencies, yet most Acoustic Metasurface (AMS) studies focus on single-frequency conditions. This study investigates how to improve sound energy harvesting efficiency by optimizing AMS designs for multi-frequency environments. We developed a model with the AMS brick that provides 16 discrete phase delay levels. We formulated an objective function incorporating multiple frequencies. By assigning weights to each dominant frequency, we proposed an optimization algorithm based on the coordinate ascent method to maximize acoustic focusing at a target point. To validate, we fabricated an AMS prototype and tested it in a controlled duct environment. The dominant frequencies and their stability were extracted using Fast Fourier Transform (FFT) and Power Spectral Density (PSD) methods. The multi-frequency optimized design improved focusing efficiency by 5.15% compared to single-frequency optimization in simulation. Experimental results showed an average increase of 2.06 dB in sound pressure, corresponding to approximately 1.61 times higher energy. In real-world noise conditions, focusing efficiency increased by up to 89.7% for mechanical noise, 10.0% for traffic noise, and 8.08% for environmental noise. These results demonstrate that multi-frequency optimization enhances the effectiveness of sound energy harvesting based on the AMS system. This allows the practical application of AMS in energy harvesting fields.

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