DEVELOPMENT OF A LOW-FREQUENCY PIEZOELECTRIC SOUND ENERGY HARVESTER USING A SINGLE-COILED ACOUSTIC METAMATERIAL CAVITY

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ABSTRACT

With urbanization, environmental pollution including noise pollution, and the demand for energy sources increase rapidly. Instead of controlling noise pollution using sound absorbers by converting it into wasted energy, the sound energy can be harvested to be utilized in various applications through different transduction methods to overcome the energy requirements of low-power instruments. While sound energy is a more abundant, clean energy source from everywhere, the harvesting process should follow step by step process as sound energy is a low energy density source. To optimally use the effect of low sound energy density, the sound energy should be amplified, then converted into electricity, and after manipulation of the harvested voltage, it can be utilized. With the aim of amplifying sound energy, various approaches are researched, and acoustic metamaterials trending as they allow manipulation of sound waves in different ways. From the beginning, different types of resonators have been used for sound amplification, while Helmholtz resonators playing a dominant role. Nowadays, the Helmholtz resonator is being modified in several ways to achieve maximum sound amplification. Considering all these aspects, in this work the Helmholtz resonator has been modified with acoustic metamaterial as a single coiled acoustic metamaterial cavity. The design of the harvester was confirmed through COMSOL multiphysics simulation analysis and the sound pressure level variation was observed using a sound meter within the tested frequency range, 100 Hz-2000 Hz. Then with the integration of the Lead Zirconate Titanate (PZT) plate, the sound energy was converted into electric energy. To evaluate the performance of the harvester, the voltage was measured through a cathode ray oscilloscope, a programmed millivoltmeter, and using a multimeter with a voltage doubler and rectifier circuits. Using a storage capacitor, the storing voltages were experimented. With sound pressure level analysis, the fundamental resonance frequency of the harvester was identified as 300 Hz while the fundamental peak of all the voltage measurements was aligned with the obtained fundamental frequency. The huge discrepancy between theoretical resonance frequency and experimental resonance frequency showed a path to modify the Helmholtz resonance frequency equation, with the modification of acoustic compliance and inertance after identifying the unsuitability of the

Helmholtz resonator equation for the larger dimension apparatus. The Helmholtz resonator equation was modified for a larger harvester with a quarter-wavelength cavity and a half-wavelength zig-zag path (that can be considered as a narrower neck) and the calculated value through the modified equation was perfectly aligned with the experimental value. The harvested voltage with the harvester was six times greater compared to the generated voltage without the harvester and therefore obtained 16 dB gain with the maximum power of 1.44 μW. Furthermore, the proposed acoustic metamaterial can be modified in several ways, such as integrating custom piezoelectric plates, rescaling to lower dimensions, integrating multiple piezoelectric plate configurations, and multiple harvester configurations in future studies.

Keywords: Noise pollution, sound energy harvesting, acoustic metamaterials, Helmholtz resonator, Piezoelectric

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