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# Resonant frequency tuning of piezoelectric energy harvesters thanks to electrical interfaces

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**Abstract.** In this presentation, we describe electrical interfaces able to tune the resonant frequency of piezoelectric energy harvesters, thanks to the inverse piezoelectric effect. We propose an analysis of the influences of the electrical interface on the dynamics of the harvester, and show how these influences might be used to both optimize the harvested power and tune the resonant frequency of the system. Finally, we present a self-powered integrated circuit that makes use of this effect in order to harvest energy from a piezoelectric energy harvester while adjusting its dynamics in real-time. The total power consumption of our circuit lies around  $1\mu\text{W}$ , its end-to-end efficiency is 94%, and it is able to adjust the resonant frequency of a highly coupled harvester from 49Hz to 60Hz. This makes our circuit a promising solution for extracting energy from piezoelectric energy harvesters while improving their robustness to aging and environmental changes thanks to its frequency tuning ability.

## Introduction

Vibration energy harvesters have been widely investigated during the last decades as a way to replace or complement batteries in order to power wireless sensor nodes. Among the various electromechanical transducers, piezoelectric energy harvesters are of interest because of their good trade-off between power density, compactness, and simplicity. This kind of harvester is usually made of a piezoelectric material deposited upon a mechanical resonator whose quality factor is usually relatively important. The power that can be harvested from such harvesters is maximized when the vibration frequency is equal to the resonant frequency of the mechanical resonator. However, in real environments, ambient vibration spectrum might vary with time. Furthermore, the resonant frequency of the energy harvester itself might also shift, because of temperature variations or aging. All those reasons may lead to a mismatch between the vibration frequency and the mechanical oscillator resonant frequency, drastically decreasing the harvested power [1].

In order to face this issue, researchers have proposed to monitor and re-adjust the resonant frequency of the harvester thanks to mechanical [2] or magnetic [3] tuning systems. They consist in applying mechanically-induced or magnetically-induced forces on the mechanical resonator in order to tune its dynamics and adjust its resonant frequency. However, most of these systems are bulky as they require motors, magnets, and screws. A considerable amount of energy is also needed every time the frequency has to be adjusted, which explains why there are still very few self-powered mechanical or magnetic tuning systems in the state-of-the-art.

Recently, some researchers proposed to adapt the dynamics of the harvester using the electrical interface connected to the piezoelectric material, thanks to the inverse piezoelectric effect [4]. In this presentation, we focus on the study and circuit implementation of such electrical tuning solutions. We detail what are the influences of the electrical interface on the harvester's dynamics, and how we used these influences to design a self-powered integrated circuit able to tune the resonant frequency of the system while simultaneously harvesting the energy.

## Results

We model the influences of the electrical interface under two terms, the electrically-induced stiffness and the electrically-induced damping. Thanks to this model, we have been able to propose a variety of electrical strategies and techniques that can be used to tune the resonant frequency of the harvester while scavenging the energy at the same time. Finally, we designed a self-powered integrated circuit in  $0.6\mu\text{m}$  XFAB technology in order to implement the proposed electrical strategy. This ASIC gathers a power path, low-power digital and analog sensors, an integrated perturb and observe MPPT algorithm consuming  $30\text{nW}$ , and a cold-start. Thanks to this circuit, we have been able to tune the resonant frequency of a custom-made highly coupled piezoelectric energy harvester from 49Hz to 60Hz, paving the way towards robust self-powered self-tuned piezoelectric energy harvesting solutions.

## References

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