



**HAL**  
open science

# Active rectification of rotational electromagnetic energy harvesting using piezoelectric elements for AC/DC power conversion improvement

Giulia Lombardi, Mickaël Lallart, Michail Kiziroglou, Eric M Yeatman

## ► To cite this version:

Giulia Lombardi, Mickaël Lallart, Michail Kiziroglou, Eric M Yeatman. Active rectification of rotational electromagnetic energy harvesting using piezoelectric elements for AC/DC power conversion improvement. International Workshop on Piezoelectric Materials and Applications in Actuators 2019 (IWPMA2019), Oct 2019, Lyon, France. hal-03219809

**HAL Id: hal-03219809**

**<https://hal.science/hal-03219809>**

Submitted on 6 May 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Active rectification of rotational electromagnetic energy harvesting using piezoelectric elements for AC/DC power conversion improvement

Giulia LOMBARDI<sup>1,\*</sup>, Mickaël LALLART<sup>1</sup>, Michail KIZIROGLOU<sup>2</sup>, Eric M. YEATMAN<sup>2</sup>

<sup>1</sup>Univ. Lyon, INSA-Lyon, LGEF, EA682, F-69621, VILLEURBANNE, FRANCE

<sup>2</sup>Department of Electrical and Electronic Engineering, Imperial College London, Exhibition Road, London, SW7 2AZ, United Kingdom

\*giulia.lombardi@insa-lyon.fr

**Abstract**— In the present work, a cooperative hybrid electromagnetic-piezoelectric energy harvester for scavenging rotational energy is presented. More precisely, in order to improve the electromagnetic transducer's AC/DC power conversion efficiency, a half-wave voltage doubler by using MOSFETs is employed. The cooperative hybrid power harvesting is then achieved by powering the MOSFETs by means of the piezoelectric system. Simulation and experimental validations are presented, demonstrating the improvement of the energy conversion efficiency of the electromagnetic transducer.

## I. INTRODUCTION

The recent expansion of wireless sensor networks along with the development of ultralow power devices have been driving research on microgenerators converting ambient energy into electricity, and therefore the development of energy harvesting systems. Among commonly utilized ambient energy sources (thermal, solar, radiofrequencies, etc.), kinetic energy harvesting has drawn great attention due to its high power density and ubiquity. In order to efficiently extract this form of energy at small scale, micro-rotational energy harvesters have been developed in the last decade [1]. Rotational energy harvesting based on piezoelectric and electromagnetic conversions are the most common ones. However, the use of piezoelectric systems in such a configuration have demonstrated to be less efficient than electromagnetic transducers due to their lower power levels. On the other hand, the typical output voltage of electromagnetic systems (order of magnitude of a few mV to hundreds of mV), yields low AC/DC conversion efficiency. A recent approach to increase the power conversion efficiency of low-power systems, consists in integrating different power sources on the same system and use one of the transducer for diode biasing [2]. Nevertheless, previous works focused on systems exploiting available energies at very different frequency levels. Hence, in this work, a hybrid cooperative electromagnetic-piezoelectric energy harvester extracting the same energy source is proposed. The work focuses on the power conversion efficiency improvement of the electromagnetic transducer employing MOSFETs powered by the piezoelectric system.

## II. MOTIVATION AND OPERATING PRINCIPLES

The system is derived from the rotational energy harvesting system previously developed by H. Fu *et al.* [3] consisting of a rotating host with a cuboidal magnet (5x5mm) placed on it. A piezoelectric cantilever beam is installed below the rotating host, with a tip magnet placed at its free end. The magnetic force between the driving magnet and the tip magnet plucks the beam periodically, making it vibrating at its resonance frequency in a frequency-up conversion manner. In order to further exploit the available energy source of the system, a coil is also placed above the rotating host; the variation of the magnetic flux induced from the movement of the rotating magnet thus causes a voltage to be induced in the coil. In order to have a preliminar evaluation of the possible power that can be extracted by the two transducers, the AC power outputs have then been measured, showing one order of magnitude of difference between the piezoelectric (10  $\mu$ W) and the electromagnetic transducer (208  $\mu$ W), demonstrating the inefficiency of piezoelectric systems for directly harvesting energy in rotational systems compared to electromagnetic ones. However, although the power that can be extracted from the electromagnetic system is potentially higher, the voltage output levels are lower than the typical diode threshold voltage (0.6 V), thus leading to high power losses when rectifying the AC voltage to a DC stage (as sensors need to be powered by DC voltage). To overcome this issue and increase the AC/DC power conversion efficiency of the electromagnetic transducer, typical diodes used for rectification can be replaced by MOSFETs that can be powered by the piezoelectric system. The resulting circuit is illustrated in Fig. 1 and consists of a half-wave voltage doubler using p-MOS and n-MOS transistors. It is then important that the negative and positive peaks of the piezoelectric and electromagnetic voltage waveforms are well synchronized in order to properly activate the MOSFETs.

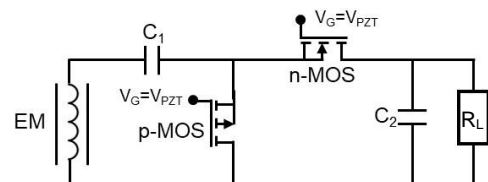


FIGURE 1. CIRCUIT SCHEMATIC

### III. SIMULATIONS AND EXPERIMENTAL VALIDATIONS

As a first validation of the cooperative piezoelectric-electromagnetic energy harvesting system, LTspice simulations have been conducted. Simulated waveforms are shown in Fig. 2, depicting the open circuit electromagnetic voltage and the resulting rectified signal when considering MOSFETs, Schottky diodes and standard silicon diodes.

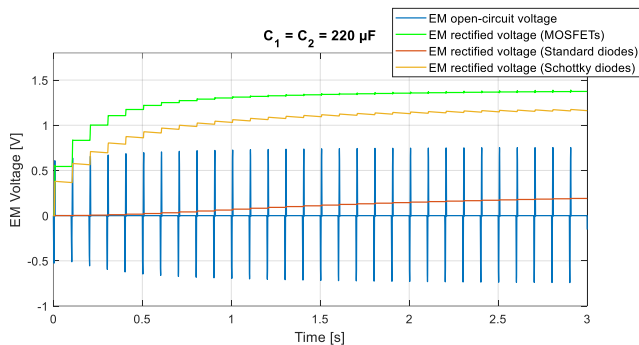


FIGURE 2. SIMULATED WAVEFORMS

Then, the system has been experimentally validated. In order to achieve voltage peaks synchronization, the rotating host have been divided into two layers, the bottom layer containing two magnets (facing opposite polarity with respect to the piezoelectric magnet) and the top layer containing one magnet (responsible of the magnetic flux change seen by the coil) as shown in Fig. 3. The two bottom magnets are responsible of a wider amplitude of the piezoelectric voltage peaks, so that they occur at the same instant of the electromagnetic voltage peaks.

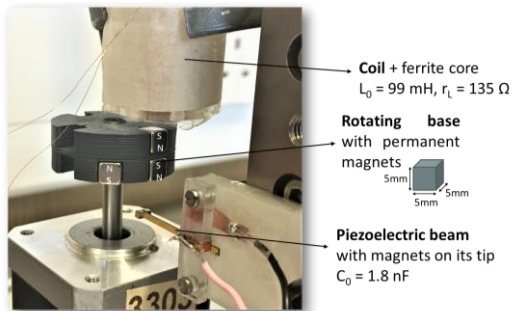


FIGURE 3. STRUCTURE SET-UP

Fig. 4 depicts the experimental waveforms of the hybrid system along with the rectified signals when considering MOSFETs (ZVNL120A, ZVP4424A), Schottky diodes (BAT48) and standard diodes (IN4148) when no load is connected to the circuit. Subsequently, the DC power with a connected load have been measured considering the three different rectification methods, as shown in Fig. 5. It is evident from the plot how the rectification in the hybrid cooperative case allows obtaining relatively higher power conversion efficiencies, particularly when compared with the non-hybrid techniques. Table I gives a comparison among the maximum output power and the conversion ratio between the DC output power ( $P_{DC}$ ) and the AC electromagnetic power ( $P_{AC}$ ) of the analyzed techniques.

TABLE I. POWER LEVELS COMPARISON

Technique	$P_{max}$	$\eta = \frac{P_{DC}}{P_{AC}} \times 100$
Hybrid cooperative rectification	124 $\mu$ W	60 %
Schottky rectification	55 $\mu$ W	26 %
Standard diodes rectification	4.65 $\mu$ W	2.25 %

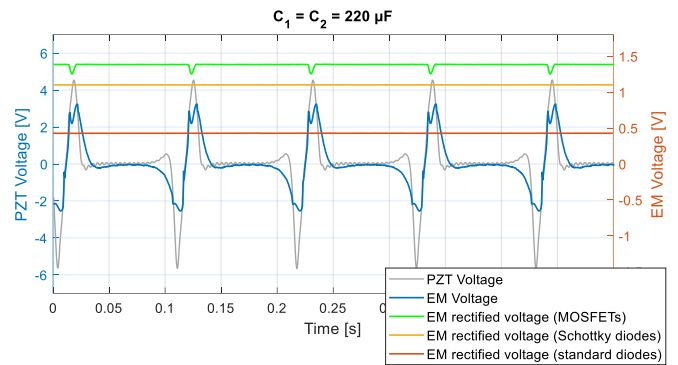


FIGURE 4. EXPERIMENTAL WAVEFORMS

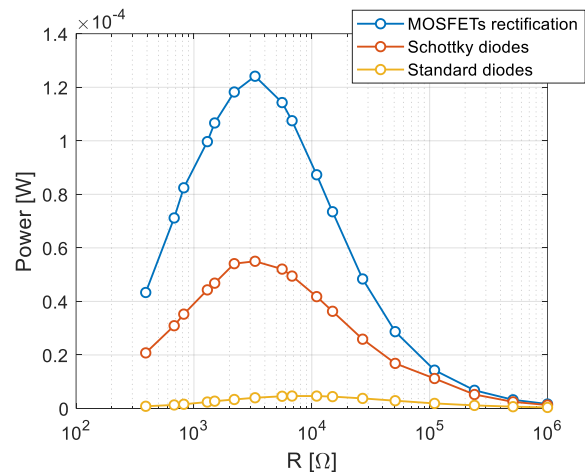


FIGURE 5. EXPERIMENTAL HARVESTED POWERS

### IV. CONCLUSION

The proposed work presented a hybrid cooperative electromagnetic-piezoelectric energy harvesting system for rectification purposes. The electromagnetic system is connected to a half-wave voltage doubler circuit employing MOSFETs powered by the piezoelectric transducer. LTspice simulations and experimental results have demonstrated the improvement of the energy conversion efficiency of the electromagnetic transducer with respect to non-hybrid and hybrid standard case.

### V. ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support from European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Grant Agreement No. 722496.

### REFERENCES

- [1] Fu, H., & Yeatman, E. M. (2018). Comparison and Scaling Effects of Rotational Micro-Generators using Electromagnetic and Piezoelectric Transduction. *Energy Technology*, 6(11), 2220-2231.
- [2] Guo, L., Gu, X., Chu, P., Hemour, S., & Wu, K. (2019). Collaboratively Harvesting Ambient Radiofrequency and Thermal Energy. *IEEE Transactions on Industrial Electronics*.
- [3] Fu, H., & Yeatman, E. M. (2017). A methodology for low-speed broadband rotational energy harvesting using piezoelectric transduction and frequency up-conversion. *Energy*, 125, 152-161.