Low-Frequency MEMS Electrostatic Vibration Energy Harvester With Corona-Charged Vertical Electrets and Nonlinear Stoppers

Y Lu, F Cottone, S Boisseau, Dimitri Galayko, Frédéric Marty, Philippe Basset

Low-Frequency MEMS Electrostatic Vibration Energy Harvester With Corona-Charged Vertical Electrets and Nonlinear Stoppers

2015 J. Phys.: Conf. Ser. 660 012003

(http://iopscience.iop.org/1742-6596/660/1/012003)

Low-Frequency MEMS Electrostatic Vibration Energy Harvester With Corona-Charged Vertical Electrets and Nonlinear Stoppers

Y Lu[1], F Cottone[1,2], S Boisseau[3], D Galayko[4], F Marty[1], P Basset[1]

[1]Université Paris-Est / ESYCOM / ESIEE Paris, France
[2]Now at University of Perugia, NIPS Laboratory, Department of Physics, Italy
[3]CEA, Leti, Minatec Campus, Grenoble, France
[4]UPMC-Sorbonne Universités / LIP6, CNRS, France

E-mail: yingxian.lu@esiee.fr

Abstract. This paper reports for the first time a MEMS electrostatic vibration energy harvester (e-VEH) with corona-charged vertical electrets on its electrodes. The bandwidth of the 1-cm^2 device is extended in low and high frequencies by nonlinear elastic stoppers. With a bias voltage of 46 V (electret@21 V + DC external source@25 V) between the electrodes, the RMS power of the device reaches 0.89 µW at 33 Hz and 6.6 µW at 428 Hz. The -3dB frequency band including the hysteresis is 223~432 Hz, the one excluding the hysteresis 88~166 Hz. We also demonstrate the charging of a 47 µF capacitor used for powering a wireless and autonomous temperature sensor node with a data transmission beyond 10 m at 868 MHz.

1. Introduction

It is widely admitted that low-frequency vibrations naturally exist in the environment and that they offer a potential resource of energy to power electronic devices or sensors. However, the efforts are always faced with the difficulty to capture low-frequency vibration energy with MEMS-based VEHs. Confined by the miniature size of the MEMS VEHs, the maximum displacement of the movable part is limited within the void space in the device, and the mass in the resonant structure is limited by its volume, which both limit the power of the device in low frequency. By using nonlinear soft springs, the operating frequency bandwidth is expanded at low frequencies [1], but the use of polymers in the device adds complexity to the fabrication process.

In this work we present a MEMS e-VEH with a large frequency bandwidth, effective from 50 Hz and obtained by the use of nonlinear external stoppers in silicon. In addition, although only soft x-ray and UV charging had been proposed as charging methods for MEMS vertical electrets [2], we demonstrate that it is also possible with a classical point-grid-plane triode Corona charging method.

2. Device Description and Fabrication

A simplified schematic of the prototype is shown in Figure 1. A moving silicon proof mass (400 µm-thick) is connected to fixed ends by linear serpentine springs. On both ends of the movable mass, stoppers standing against clamped-clamped elastic beams have been added [3]. At sufficient acceleration levels, the stoppers on the ends of the movable mass hit the elastic beams, which deforms them; this results in a low-frequency and a wideband response of the device.

The fabrication process is derived from [4]. The silicon layer is patterned with an Al mask using a DRIE process, and is anodicly bonded with a glass substrate. A layer of parylene is deposited all over the device. The parylene layer on the movable part is negatively charged with the corona charging setup while the parylene layer on the fixed electrodes is not charged.

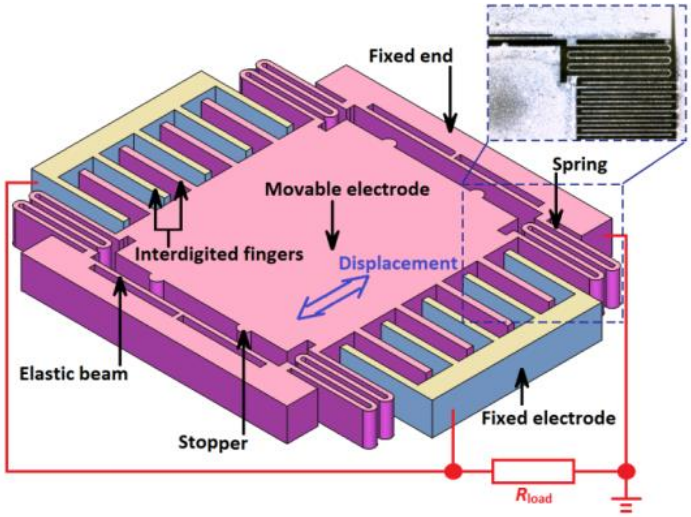

Figure 1. Simplified schematic of the silicon layer of the electrostatic energy harvester. The nonlinear spring system consists of the linear serpentine springs and the nonlinear elastic beams standing against stoppers.

3. Device Characterization

3.1. Built-in voltage measurement

In order to measure the built-in bias voltage (V_{bias}) provided by the electret, we propose to use the circuit shown in Figure 2(a). The saturation value of the voltage across the storage capacitor C_v is given by:

$$V_{\text{store}} = V_{\text{bias}}\left(1 - \frac{C_{\min}}{C_{\max}}\right)$$

where C_{min} and C_{max} are the minimum and the maximum values of the variable capacitance C_{var}. The saturation value of V_{store} is 11 V as given by the measurement shown in Figure 2(b), and the measurement of capacitance C_{var} indicates a minimum of 50 pF and a maximum of 105 pF respectively. Thus, the internal voltage provided by the electret is about V_{bias} = 21 V.

However, the device could stand for much higher bias voltage. In order to fully demonstrate the capability of the prototype, we also performed experiments with an additional DC bias at 25 V in series with the prototype to investigate its performance with a higher voltage bias (up to 46 V).

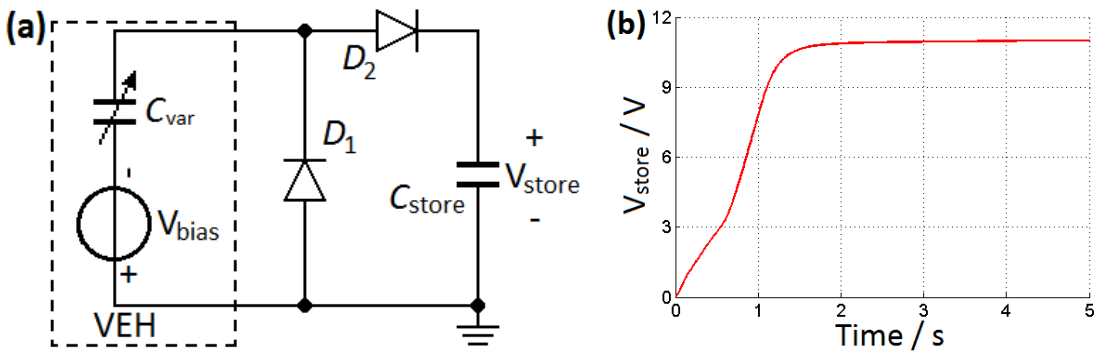

Figure 2 (a). Circuit for built-in voltage measurement of the electret layer, where C_{store}=1.1 nF; (b). Evolution of V_{store} at 2.0 g_{RMS}, 145 Hz.

3.2. Characterization of the performance in frequency domain

The device is connected in series with a load resistor of 6.65 MΩ and is subjected to power measurement with frequency sweeping. The device is firstly tested at 0.1 g_{RMS} for the natural frequency measurement f_0, which is observed at f_0 = 104 Hz.

Figure 3 gives the RMS power against the frequency at higher accelerations (0.5 and 2.0 g_{RMS}). Typical spring stiffening effects and hysteresis are observed, which is caused by the impacts between the stoppers and the nonlinear elastic beams.

With the bias voltage of 21 V (electret alone), the maximum output power at 0.5 g_{RMS} is 0.48 μW, and the one at 2.0 g_{RMS} reaches 1.3 μW. If the hysteresis is excluded, the maximum power at 0.5 g_{RMS} is 0.2 μW, while it reaches 0.4 μW at 2.0 g_{RMS}. An output power of at least 0.1 μW can be harvested within the 45~450 Hz frequency band including the hysteresis frequency span.

With a higher bias voltage of 46 V (electret at 21 V and external DC bias at 25 V), both the power and the bandwidth of the device are improved. The power reaches 1 μW at 0.5 g_{RMS} just below the frequency span of hysteresis, and reaches 2.1 μW at 161 Hz. At 2.0 g_{RMS}, the power reaches 6.6 μW at 428 Hz, and the power before reaching hysteresis is 2.4 μW. Within the frequency range of 29~432 Hz, the output power is superior to 0.6 μW. Finally, the -3 dB frequency bands with and without hysteresis are 223~432 Hz and 88~166 Hz, respectively.

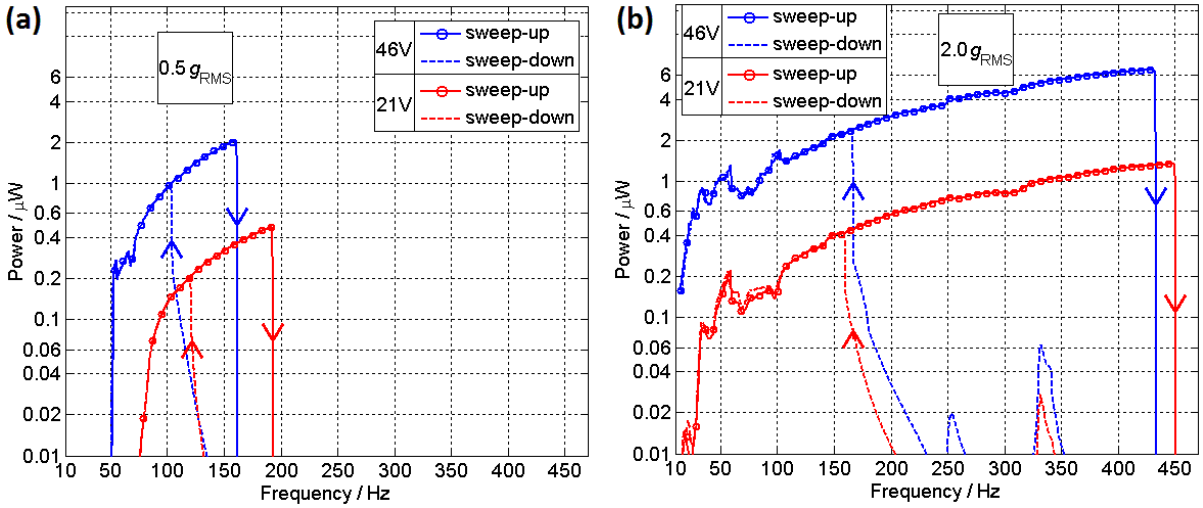

Figure 3. RMS output power vs. frequency for bias voltages of 21 V (electret alone) and 46 V (electret@21V + DC external bias@25V) at 0.5 g_{RMS} (a) and 2.0 g_{RMS} (b), R_{load}=6.65 MΩ.

3.3. Powering sensors and wireless data transmission

The power supply of a wireless temperature sensor node supplied by our energy harvester is shown in Figure 4(a). The output power of the device without any additional DC bias (electret alone – V_{bias} = 21 V) is rectified with a diode bridge, and stored in a 47-μF capacitor. This capacitor powers a low-power sensor node made of a temperature sensor, a MSP430 microcontroller and a RF chip working at 868 MHz (CC430). A low-power Schmitt trigger (Switch module) [5] is used to detect when enough energy has been stored in the capacitor to supply the wireless sensor node. The Switch module reads the voltage across C_s (U_{Cs}) and closes the switch to supply the wireless sensor node as soon as U_{Cs} reaches 3.8 V. The switch is re-opened when U_{Cb} falls below 2.8 V in order not to uselessly discharge C_s. The power consumption of the switch module is lower than 40 nA at 3 V. A photograph of the experimental setup is also shown in Figure 4(b).

Figure 4(c) shows the voltage evolution during a series of data transmission experiment. The storage capacitor C_s is charged with the e-VEH prototype working at 300 Hz with an acceleration of

2.0 g_{RMS}. The initial voltage across C_s rises from 0 V to 3.8 V in 7.2 min. This corresponds to a stored energy of 334 µJ; then, the average harvested power stored in C_s is 0.77 µW. U_{Cs} = 3.8 V is detected by the Schmitt trigger which closes the switch (PMOS transistor) to supply the wireless sensor node. The wireless sensor wakes up, performs its temperature measurement and sends the information wirelessly. This operation occurs twice each time the sensor node is turned on. The voltage drop for a measurement and a transmission up to 10 m is 0.7 V, which corresponds to an energy consumption of 102 µJ (155 µJ for two successive measurements and RF emissions). Finally, it takes about 2 min to recharge C_s from 2.8 V to 3.8 V, which corresponds to an average harvested power of 1.27 µW. Then, a new measurement cycle (2 measures and 2 data emissions) restarts… and so on.

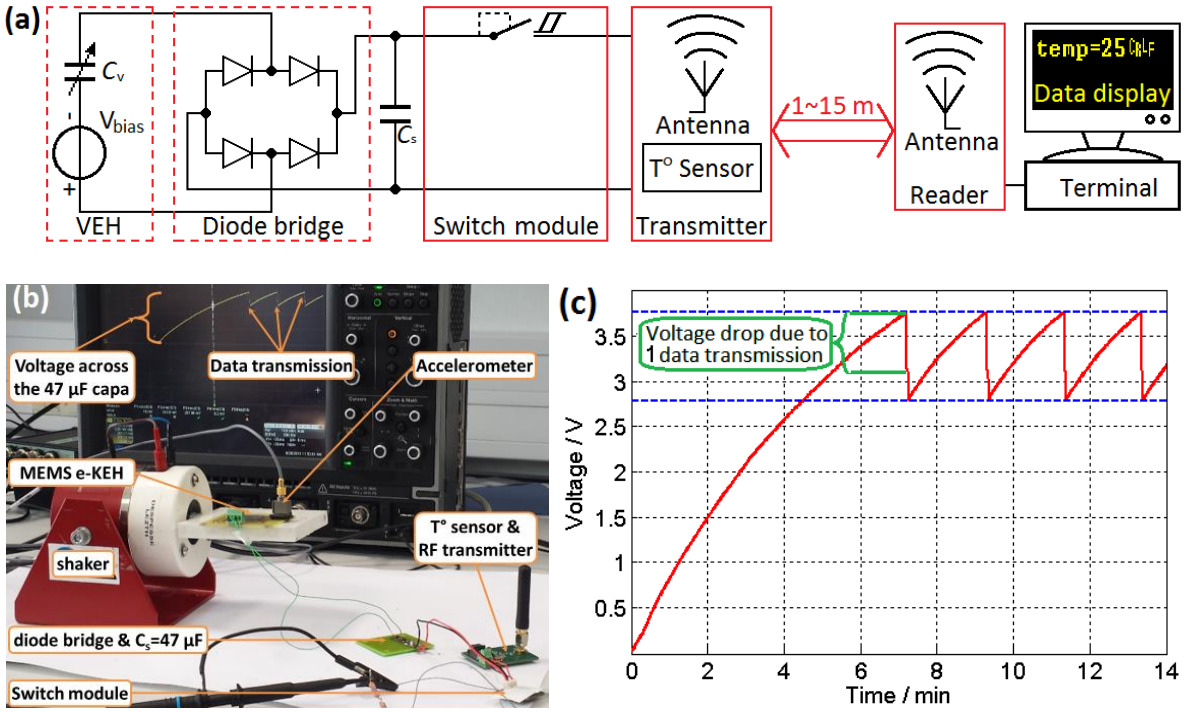

Figure 4 (a). Schematic and (b). photograph of the experiment of data transmission; (c). voltage evolution on C_s with time during the experiment.

4. Conclusion

We have reported on a low-frequency and large bandwidth 1-cm² silicon-based e-VEH prototype with Corona-charged vertical electrets and nonlinear external stoppers. The device has been connected to a diode-bridge capacitor circuit to supply a wireless sensor node based on a CC430 chip with an emission of a temperature measurement every 2 minutes.

Acknowledgments

This work is sponsored by the *SATT-IDFINNOV*.

References

[1] D. Miki, M. Honzumi, Y. Suzuki, et al, *Proc. of IEEE MEMS'10*, pp. 176-179, 2010
[2] Y. Suzuki, *IEEJ Trans. Electrical & Electronic Eng.* **6** pp 101-111, 2011
[3] F. Cottone, P. Basset, F. Marty, et al, *Proc. of IEEE MEMS'14,* pp. 385-388, 2014
[4] Basset P, Galayko D, Cottone F, et al. *„J. Micromech. & Microeng.*, **24** 035001, 2014
[5] STMicroelectronics/CEA Patent pending