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Electrostatic Vibration Energy Harvester Pre-charged Wirelessly at 2.45 GHz

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Abstract. This paper reports the design, fabrication and experiments of an electrostatic vibration harvester (e-VEH), pre-charged wirelessly for the first time by using an electromagnetic waves harvester at 2.4 GHz. The rectenna uses the Cockcroft-Walton voltage doubler rectifier. It is designed and optimized to operate at low power densities and provides high voltage levels: 0.5 V at 0.5 µW/cm² and 0.8 V at 1 µW/cm². The e-VEH uses the Bennet doubler as conditioning circuit. Experiments show 23 V voltage across the transducer terminal when the harvester is excited at 25 Hz by 1.5 g of external acceleration. An accumulated energy of 275 µJ and a maximum power of 0.4 µW are available for the load.

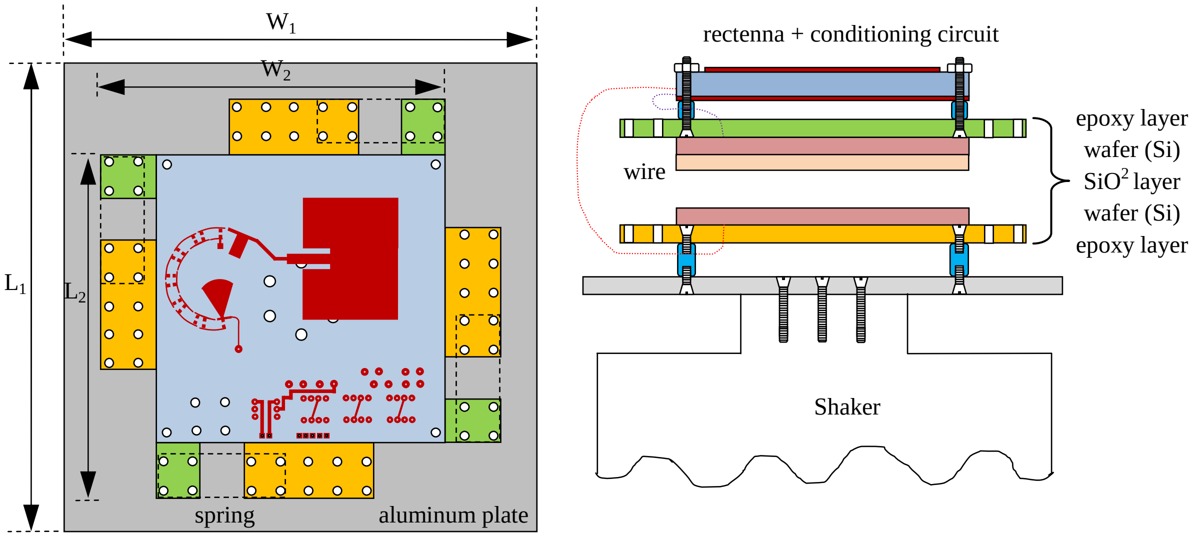
1. Introduction

Advances in wireless communications and low consumption electronics in recent decades had contributed to the emergence of sensors and connected objects in different fields. An exponential growth of the number of devices is expected with the advent of the Machine-to-Machine (M2M) and the Internet of Things (IoT). The energy autonomy of such devices constitutes one of the main obstacles before reaching the full mobility. Instead of traditional batteries which require periodic replacement or recharging and raises recycling issues, the energy harvesting consisting to convert the energy of ambient sources such as vibrations, electromagnetic waves, thermal, solar and wind into electrical energy, became a potentially promising solution. From these ambient sources, the mechanical vibration energy is of particular relevance due to its availability. The vibration harvesters are based on the transduction mechanism, and there are typically of three kinds: electromagnetic, piezoelectric and electrostatic. In electrostatic vibration energy harvesters (e-VEHs), the mechanical energy is converted into electricity by a mechanical attraction force due to charged variable capacitor plates. This force opposes the motion of the mobile plate. The generated power from mechanical to electrical conversion is proportional to the square of the accumulated quantity of charge in the capacitor. Therefore, an external source providing sufficient voltage is necessary to convert vibrations into electricity in a sufficient manner. One solution consists to use an electret layer [1]. Another solution consists in using a transducer's pre-charge containing a power source and a conditioning circuit which generates the bias voltage itself and then creates a force between the two plates of the variable capacitor [2].

Most conditioning circuits reported in the literature requires inductive elements and switches [3] to generate a high bias voltage. However, inductive elements are not compatible with batch manufacturing process and switches require additional power-consumption control circuits. Recently issued, a conditioning circuit based on the Bennet doubler generated high bias voltage without using any switch or inductor [4]. The outline of this paper is as follows. Section 2 describes the electrostatic vibration energy harvester and section 3 reports the experimental results of the full circuit. Section 3 concludes the paper.

2. Description of the electrostatic vibration energy harvester

The schematic drawing of the e-VEH prototype is shown in figure 1. The device includes a variable capacitor and a Bennet's doubler conditioning circuit. The top view (Fig. 1 (a)) shows the rectenna and the conditioning circuit on the same substrate, which is linked to the mobile plate of the variable capacitor with four teflon bolts (Fig. 1 (b)). The variable capacitor is made by 2 circular doped silicon wafers of 100 mm diameter and 0.5 mm thickness, pasted on square epoxy board of 1.5 mm thickness. The wafer of the mobile plate is provided with a SiO_2 insulating layer of 50 µm thickness to prevent short circuits with the second wafer. The second plate of the variable capacitor is fixed to a shaker. Four flat metal springs, of 6 mm length and 15 mm width, are used to link the two plates of the variable capacitor, one on each side of the epoxy layer.

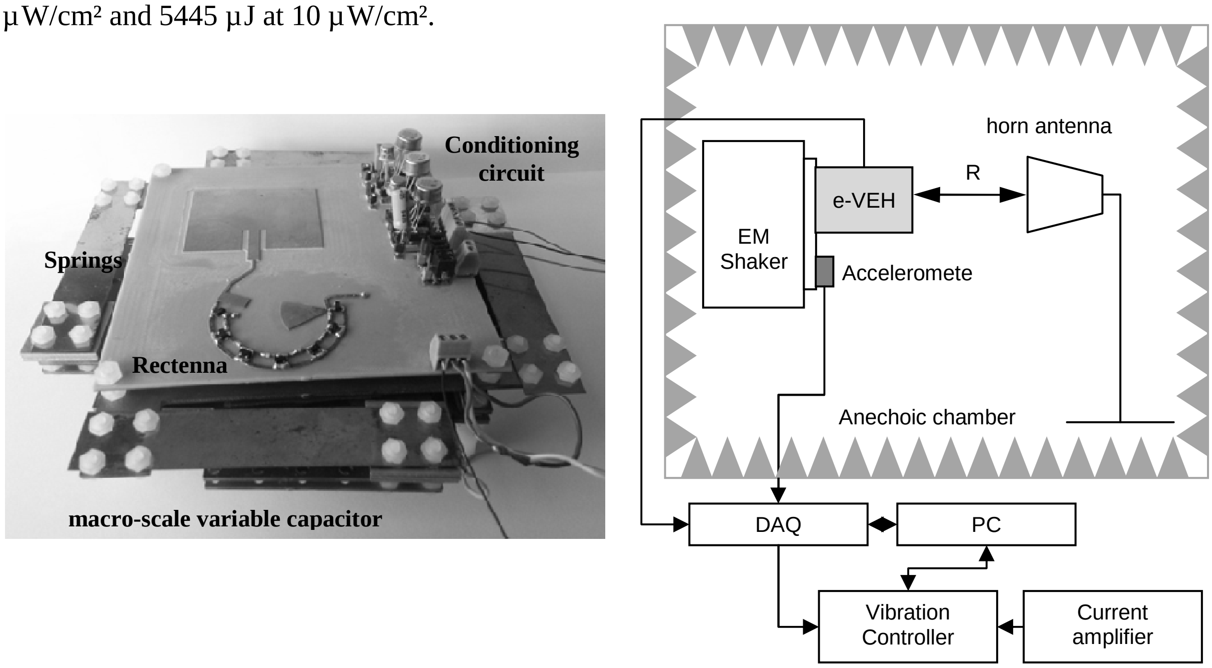


(a) (b)

Figure 1. Geometry of the proposed e-VEH: L_1= W_1 =150, L_2=120, W_2=120 (dimensions are in mm). Top view (a) and profil view (b).

3. Experiments of the e-VEH full system

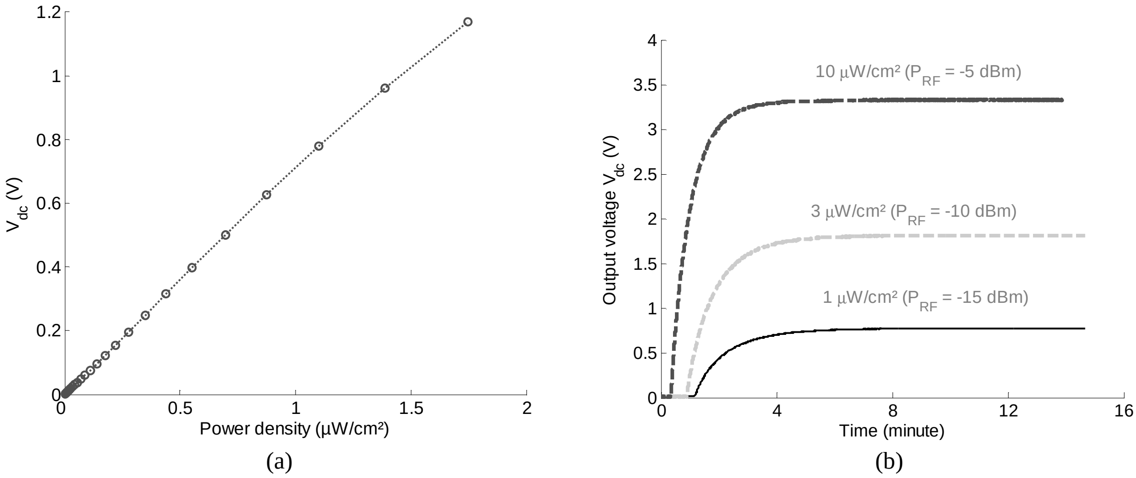
The proposed harvester was achieved and measured. The photograph of the prototype is depicted on Fig. 2 (a). The experiments were carried out using the macro-scale resonant variable capacitor described in the previous section. The resonance frequency was 25 Hz. The measured unbiased transducer capacitance variation of 1.5 g amplitude at 25 Hz frequency was: C_{max}/C_{min} = 250pF / 40 pF (η = 6.25). Figure 2 (b) shows the schematic diagram of the used experimental setup. The e-VEH prototype is mounted on a shaker (Bruel & Kjaer type 7541) and placed in an anechoic chamber at a distance R = 1.5 meters from a transmitting horn antenna, where the far field condition is satisfied. An accelerometer, adhered to the shaker, is used to control and then regulate the acceleration. The experiment was carried using external vibrations at 25 Hz with acceleration amplitude of 1.5 g. The rectenna uses the Cockcroft-Walton circuit proposed by authors in [5]. It provides 0.5 V at 0.5 µW/cm², 0.8 V at 1 µW/cm² and 1.17 V at 1.75 µW/cm², as shown in Fig. 3 (a). The measured voltage evolution, over a capacitive load of 1 mF, for different power densities from 1 to 10 µW/cm² is depicted in Fig. 3 (b). The capacitor load stores energy of about 281 µJ at 1 µW/cm², 1620 µJ at 3 µW/cm² and 5445 µJ at 10 µW/cm².



(a) (b)

Figure 2. Photograph of the prototype (a) and schematic diagram of the used experimental setup (b).

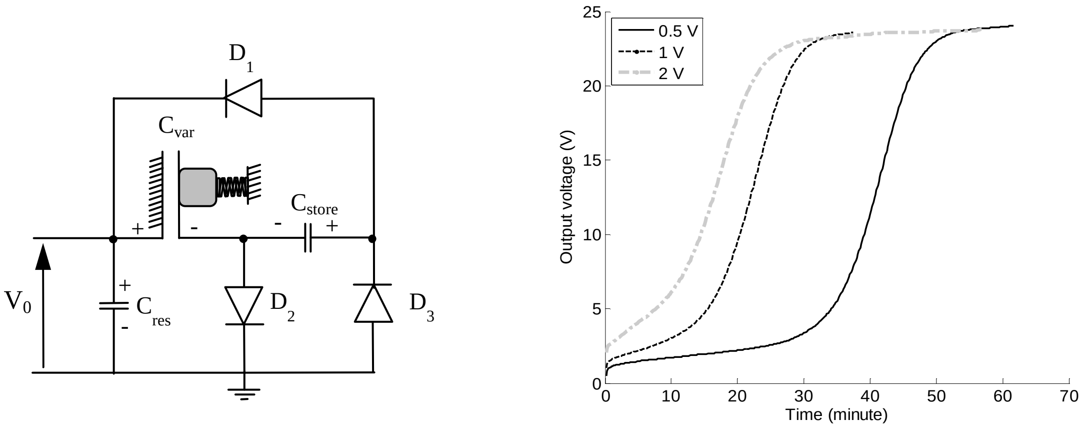
The Bennet's doubler used as conditioning circuit is shown in Fig. 4 (a). The circuit contains three capacitors, the variable capacitor C_{var}, C_{res} = 1 µF and C_{store} = 47 nF and three diodes D_1, D_2 and D_3 (JPAD5). The initial pre-charge V_0 applied to C_{res} is supplied by the Cockcroft-Walton rectenna. The operation of the Bennet's doubler is described in [4].



(a) (b)

Figure 3. Measured output voltage vs. power density (output load = 100 MΩ, f = 2.4 GHz) (a). Measured voltage evolution vs. time over a capacitive load of 1 mF (b).

The measured voltage evolution across the reservoir capacitor C_{res} = 1 µF at several pre-charge voltages are shown in Fig. 4 (b). The output voltage progressively increases up to 23 V, where saturation occurs. This increase of voltage across C_{res} corresponds to the accumulated energy. The saturation of the voltage across C_{res} is due to the spring-softening effect induced by the electromechanical coupling [4]. Indeed, the resonance frequency of the harvester decreases when the self biasing by the conditioning circuit increases, and the frequency becomes outside the mechanical system bandwidth.



(a) (b)

Figure 4. Bennet's doubler conditioning circuit (a). Measured evolution of voltage across C_{res} = 1 µF for several bias voltages 0.5, 1 and 2 V with 25 Hz and 1.5 g external vibrations (b).

4. Conclusion

This paper presents the first experiments of an electrostatic vibration energy harvester start-up using RF waves. The RF harvester consists on a Cockcroft-Walton rectenna at 2.4 GHz. The circuit was fabricated and validated. It provides 0.8 V at 1 µW/cm² and 1.8 V at 3 µW/cm². The Bennett doubler is used as conditioning circuit. It doesn't need any inductive element or switch. Experiments show 23 V voltage across the transducer terminal, when the harvester is excited at 25 Hz by 1.5 g of external acceleration. An accumulated energy of 275 µJ and a maximum power of 0.4 µW are available for the load.

References

[1] Y. Lu, F. Cottone, S. Boisseau, F. Marty, D. Galayko and P. Basset, "A Nonlinear MEMS Electrostatic Kinetic Energy Harvester for Human-Powered Biomedical Devices", *AIP Applied Physics Letters* 107, 253902, 2015.

[2] E O'Riordan, D Galayko, P Basset and E Blokhina, "Complete electromechanical analysis of electrostatic kinetic energy harvesters biased with a continuous conditioning circuit", *Sensors and Actuators A: Physical* 247, 379-388, 2016.

[3] P. Basset, E. Blockhina and D. Galayko, "Electrostatic Kinetic Energy Harvesters", *Smart adaptive systems on silicon series*, 244 pages, March 2016, Wiley-ISTE.

[4] V. Dorzhiev, A. Karami, P. Basset, F. Marty, V. Dragunov, and D. Galayko, "Electret-free micromachined silicon electrostatic vibration energy harvester with the Bennet's Doubler as conditioning circuit," *IEEE Electron Device Letters*, vol. 36, no. 2, pp. 183-185. 2015.

[5] H. Takhedmit, H. Kilani, L. Cirio, P. Basset, and O. Picon, "Design and experiments of a 2.4-GHz voltage multiplier for RF energy harvesting," *Proc. PowerMEMS*, pp. 448-51. 2012.