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# Design and test of a Bennet's doubler device with mechanical switches for vibrational energy harvesting

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**Abstract.** In this work, we demonstrate that the use of self-synchronized mechanical switches in replacement of diodes into electrostatic vibration energy harvesters (e-VEH) can lead to better power generation. Indeed, mechanical switches have the advantage of no leakage current and no threshold voltage. As a proof of concept, we use the Bennet's doubler electrostatic generator. The proposed e-VEH is composed of two variable capacitors triggered by a central electrode taken as an inertial mass. Ambient vibrations induce inertial forces on the central electrode, as a result a voltage doubling is obtained at each operating cycle. The mechanical switches are directly fixed to the moving electrode. In addition, no dedicated pre-charge is required: the system starts with ambient electrical charges. The device is fabricated and tested under harmonic motion. A comparison between the proposed design and those using diodes under the same operating conditions shows an experimental direct increase of the harvested electrical power of around 28%.

## 1. Introduction

Vibration energy harvesting (VEH) from mechanical motions is becoming a promising technology that allows a better spreading of smart and micro-systems in many new applications. This energy source offers extraordinary capability to new technological paradigms, such as the Internet of Things and Smart Cities.

Many VEH devices have been developed during the last decade. Several transduction mechanisms were tested to transform the kinetic energy of the environment into useful electrical energy. Three types of transduction dominate the major part of the published designs: (i) Electromagnetic transduction [1] described by a high power generation, but require complex design and large dimensions, (ii) Piezoelectric and smart materials [2, 3, 4] characterized by high power generation density, but require special and costly fabrications steps, and (iii) Electrostatic transduction [5] known for its high integration, but generally generates low power density.

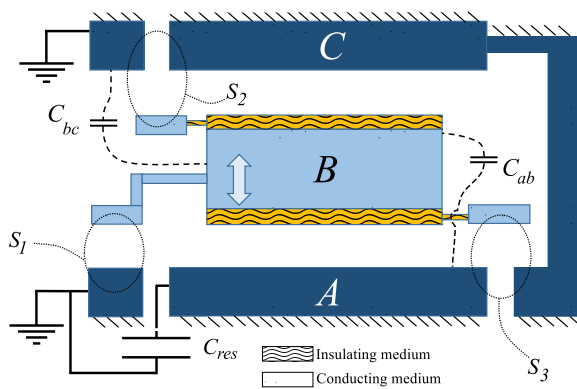
In 1787, Bennet proposed the principle of an electrostatic generator by continuously doubling the charges on a conductor after repeating a given sequence of contacts between three plates [6]. Recently, Queiroz [7] proposed to harvest kinetic energy based on the Bennet doubler principle where the contacts are replaced by diodes. This new conditioning circuit for electrostatic Vibration Energy Harvesters (e-VEH) was used for the first time with a capacitive MEMS transducer dedicated to harvest kinetic energy from vibrations by Dorzhiev et al. [8].



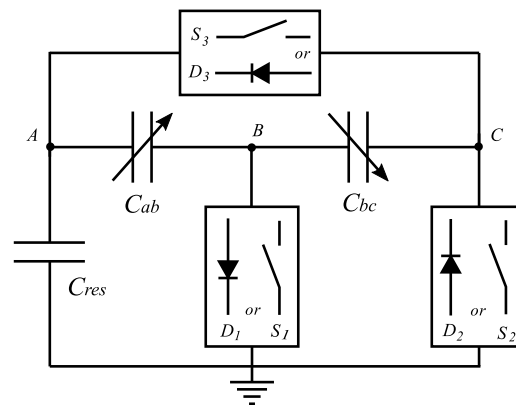
In this work we aim at designing and testing the first Bennet's electrostatic generator dedicated to vibration energy harvesting where the diodes introduced by Queiroz et al [7] are removed. Indeed, by replacing the diodes with self-synchronized mechanical switches, we get the advantage of no leakage current and no threshold voltage. An expected increase of the power generation is sought along with an elimination of the device control during the operating cycle.

## 2. Bennet doubler for e-Vibration Energy Harvesting with self-synchronized mechanical switches

The functional representation of the proposed Bennet's doubler for e-VEH is shown in Figure 1. It is composed by two variable capacitors  $C_{ab}$  and  $C_{bc}$ , and a restoring capacitor  $C_{res}$ . They are made of 3 aluminum electrodes  $A$ ,  $B$  and  $C$  covered with a Parylen layer (Figure 1). Three mechanical switches  $S_1$ ,  $S_2$  and  $S_3$  are also implemented to play the role of classically used diodes  $D_1$ ,  $D_2$  and  $D_3$ , respectively. The equivalent electrical circuit with diodes or mechanical switches is shown in Figure 2.



**Figure 1.** Functional representation of the e-VEH Bennet's doubler device with mechanical switches.



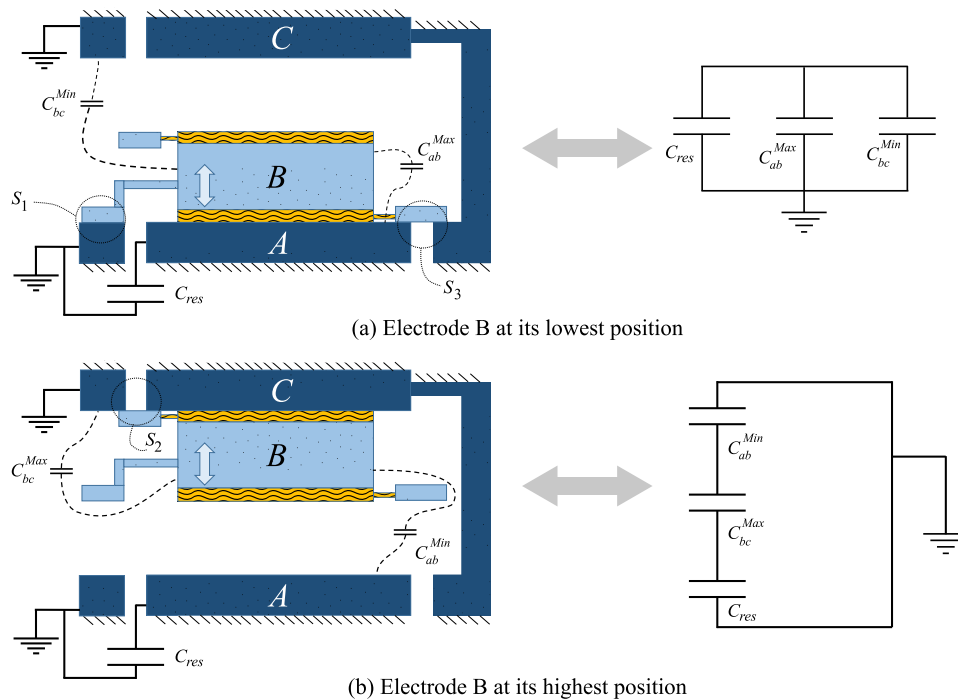
**Figure 2.** Electrical circuit of the e-VEH Bennet's doubler device with diodes or mechanical switches.

The basic principle is the following: the central electrode  $B$  moves between electrodes  $A$  and  $C$  thanks to inertial forces due to external excitations. As shown in Figure 3, the induced motion generates out-of-phase variations of  $C_{ab}$  (between  $A$  and  $B$ ) and  $C_{bc}$  (between  $B$  and  $C$ ). For our demonstrator, the value of  $C_{ab}$  varies between 20pF and 80pF, while  $C_{bc}$  varies between 1020pF and 1100pF.

The stoppers  $S_1$  and  $S_2$  are used as mechanical switches, which relate respectively the electrodes  $B$  and  $C$  to the ground. The mechanical switch  $S_3$  relates electrode  $C$  to  $A$  when  $B$  is at its lowest position with respect to  $A$ .

## 3. Operating cycle of the e-VEH Bennets doubler device

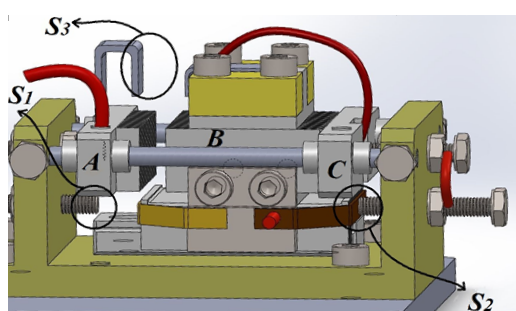
Initially, there are some charge  $Q$  on the electrode  $A$  due to the ambient electromagnetic noise. The operating cycle starts when the central electrode  $B$  is at its lowest position with respect to  $A$ , which activates the switch  $S_1$ , connecting  $B$  to the ground (Figure 3-a). This brings an induced charge  $-Q$  on  $B$  and turns the capacitor  $C_{ab}$  to its maximum value  $C_{ab}^{Max}$ , and the capacitor  $C_{bc}$  to its minimum value  $C_{bc}^{Min}$ . At this configuration, all the capacitances are in parallel. Then the electrode  $B$  moves towards  $C$  under inertial forces. When  $B$  reaches  $C$  at its highest position (Figure 3-b), the electrode  $C$  is grounded through the activation of the switch  $S_2$ , and a charge  $+Q$  is induced on  $C$ . All the capacitances are now connected in series, and  $C_{ab}$  and  $C_{bc}$  are set to  $C_{ab}^{Min}$  and  $C_{bc}^{Max}$ , respectively.



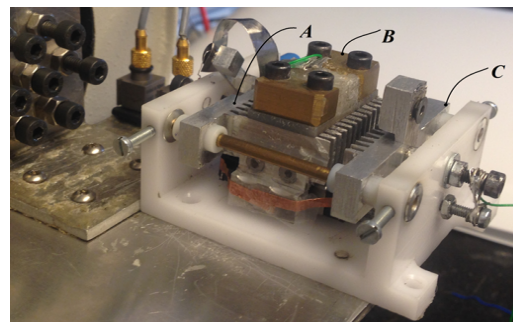
**Figure 3.** Operating cycles of the e-VEH Bennet’s doubler device with the corresponding equivalent circuit.

The last step of this cycle is initiated when the electrode *B* moves back to its lowest position. There, *B* is grounded again through *S*<sub>1</sub> and *A* is connected to *C* through *S*<sub>3</sub> (Figure 3-a) and the new *B* electrode’s charge is equal to  $-2Q$ . All the capacitances are again in parallel. The operating cycle is repeated again and again, to double the charge at each period.

**4. Experimental validation of the e-VEH Bennets doubler with mechanical switches**



**Figure 4.** 3D model of the fabricated e-VEH Bennet’s doubler device.

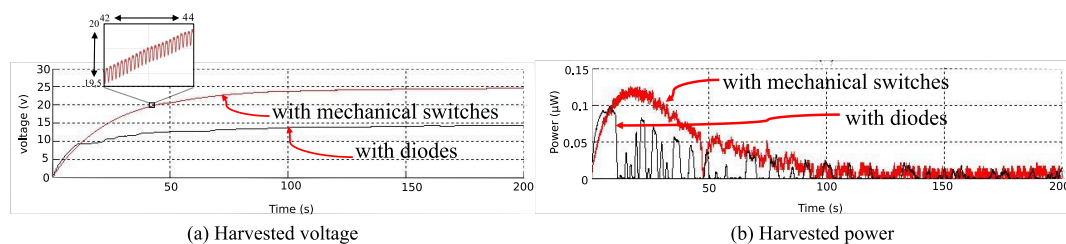


**Figure 5.** Fabricated e-VEH Bennet’s doubler with aluminium and polyamide materials mounted with a shaker.

The e-VEH Bennet’s doubler device is modeled (Figure 4) and fabricated (Figure 5) according to the described operating cycle in the previous section. The general dimensions of the device are 5cm×3cm×2cm. Interdigitated electrodes with triangular shape is adopted on the two faces of

electrode  $B$  and the active faces of electrodes  $A$  and  $C$ , so that an increase of the extrema values of  $C_{ab}$  and  $C_{bc}$  is obtained. The device is mounted to a shaker that is excited with harmonic motion.

The objective of these experiments is to validate the proposed proof of concept by comparing the designed device with a similar device using a set of diodes replacing the mechanical switches. Using the same external excitation conditions (12Hz at  $1g_{rms}$ ) for both designs, we measure the voltage across  $C_{res}$ . In Figure 6-a, we plot the voltage variations as the number of cycles is increasing. As expected, a voltage saturation is observed for both designs (with mechanical switches and with diodes). However, for the mechanical switches design a voltage gain of almost 80% is observed (25V against 14V). The harvested power is measured by deriving the instantaneous electrical energy in  $C_{res}$ . The results, shown in Figure 6-b, depict an increase of around 28% in favor of the mechanical switch design.



**Figure 6.** Measurements of voltage and harvested power across  $C_{res}$  for both diode and mechanical switch designs.

## 5. Conclusion

Using an electrostatic vibration energy harvester (e-VEH) and adopting a Bennet's doubler design as conditioning circuit, we showed that replacing the classically used diodes by self-actuated and self-synchronized mechanical switches leads to a performance increase of the harvester. We designed and fabricated a new e-VEH and conduct a series of experiments to compare diode and mechanical switch based designs. The experimental results showed that a net increase of the saturation voltage was observed around 80%. This corresponds to a harvested power improvement of 24%. The power generation profile was not only higher for mechanical switches design, but also showed a smoother behavior as function of time leading to further increase in terms of total harvested energy. More analysis are needed to estimate and reduce the mechanical losses and to reduce the device size.

## 6. References

- [1] Naifar S, Bradai S, Viehweger C and Kanoun O 2016 *Measurement* In Press.
- [2] Marzencki M, Defosseux M and Basrou S 2009 *J. MEMS* **18** 1444-1453
- [3] Li H, Tian C, and Deng Z D 2014 *Applied Physics Reviews* **1** 041301
- [4] Jemai A, Najar F, Chafra M and Ounaies Z 2016 *Composite Structures* **135** 176190
- [5] Amri M, Basset P, Cottone F, Galayko D, Najar F and Bourouina T 2011 *Proc. PowerMEMS2011* Seoul 15-18 Nov.
- [6] Bennet A and Kaye R 1787 *Philosophical Trans. of the Royal Society of London* **77** 288-296
- [7] de Queiroz A C M 2010 *53rd IEEE Int. Midwest Sym. on Circuits and Systems* Seattle WA 1-4 Aug.
- [8] Dorzhiev V, Karami A, Basset P, Marty F, Dragunov V and Galayko D 2015 *IEEE Elec. Device Letter* **36** 183135