A Low Power Multiple Energy-Shot Load Interface for Electrostatic Vibrational Energy Harvesters

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Abstract

Electrostatic vibrational energy harvesting (e-VEH) is an appealing power source for self powered wireless sensors. Earlier studies demonstrated conditioning of capacitive transducers used within e-VEH through rectangular QV conditioning circuits (CC). A fundamental characteristic of such CC is that the power of conversion is function of the instantaneous value of its internal energy. A load interface (LI) is proposed which achieves a smart control of the internal energy by setting the CC storage capacitor (C_{res}) voltage within an interval maximizing the power of conversion. This is extremely vital for circuits with self-increasing biasing, as Bennets doublers.

Introduction

- E-VEHs use variable MEMS capacitors moving freely with an external mechanical vibration, leading to disturb the CC charges thus accumulating energy on a reservoir capacitor (C_{res}).
- The harvested energy on C_{res} can exhibit a high voltage as well as large - yet slow - variations. Thus, a LI is needed as an intermediate stage between the CC and the voltage regulator.
- The proposed LI has two main roles:
  - (i) transfers the energy from C_{res} of the CC towards the load buffer capacitor (C_{buffer}).
  - (ii) ensures that V_{res} voltage is maintained within the optimum interval.
- With V_{res} optimum interval around 30V high for some capacitive transducers, regulation of V_{res} can challenging. Moreover, typical generated power of a e-VEH is not more than few tens of microwatt, and the power overhead available for the LI operation is not more than 1-2 μW.

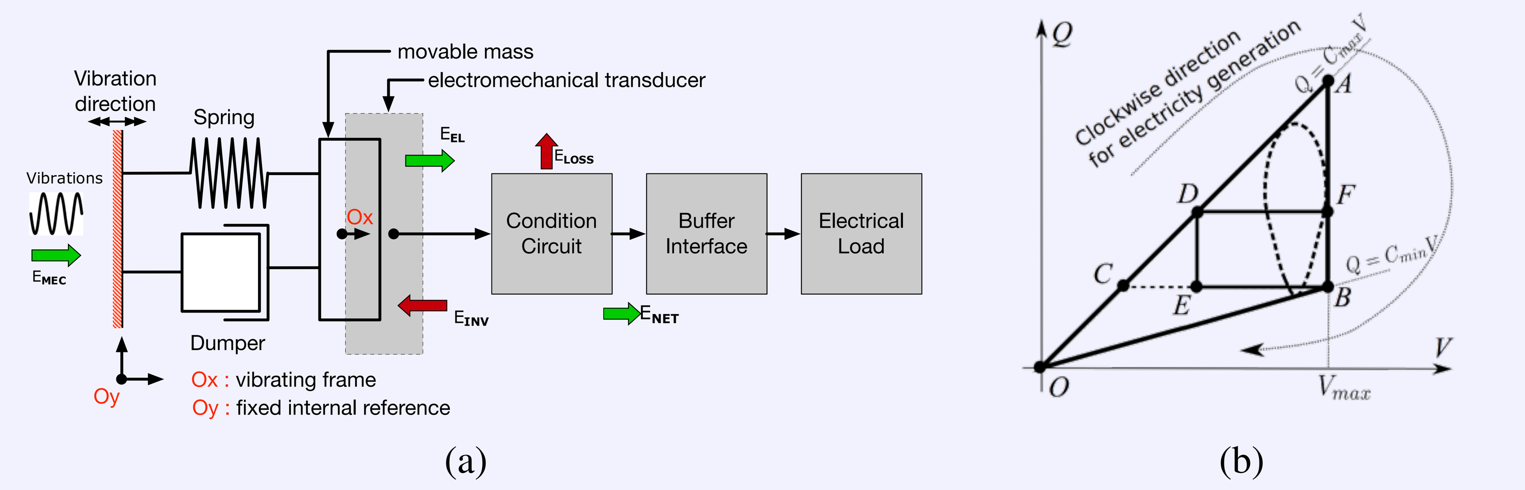

Figure 1: E-VEH system blocks(a). Charge-Voltage (QV) digram for conditioning of capacitive transducers in KEHs: OCB (constant-Q), OAB (constant-V), DFBE (rectangular) and tear drop cycle [1] (b).

Vibrational Energy Harvester System Description

- The e-VEH presented is a single MEMS capacitor with Bennet's doubler CC implementing a rectangular QV. The variable MEMS capacitor has $C_{max} = 175pF$ and $C_{max}/C_{min} = 2.78$ at 187Hz and capable of producing up to $1.80\mu W$ @ 4g/187Hz harmonic external acceleration if $7V < V_{res} < 10V$ [2, 5].
- The harvested energy rate is maximized by containing V_{res} within an optimum interval. [1, 5].

Energy removed from C_{res} to drop its voltage from V_{resH} to V_{resL},

$$\Delta W = \frac{1}{2} C_{res}(V_{resH}^2 - V_{resL}^2) \quad (1)$$

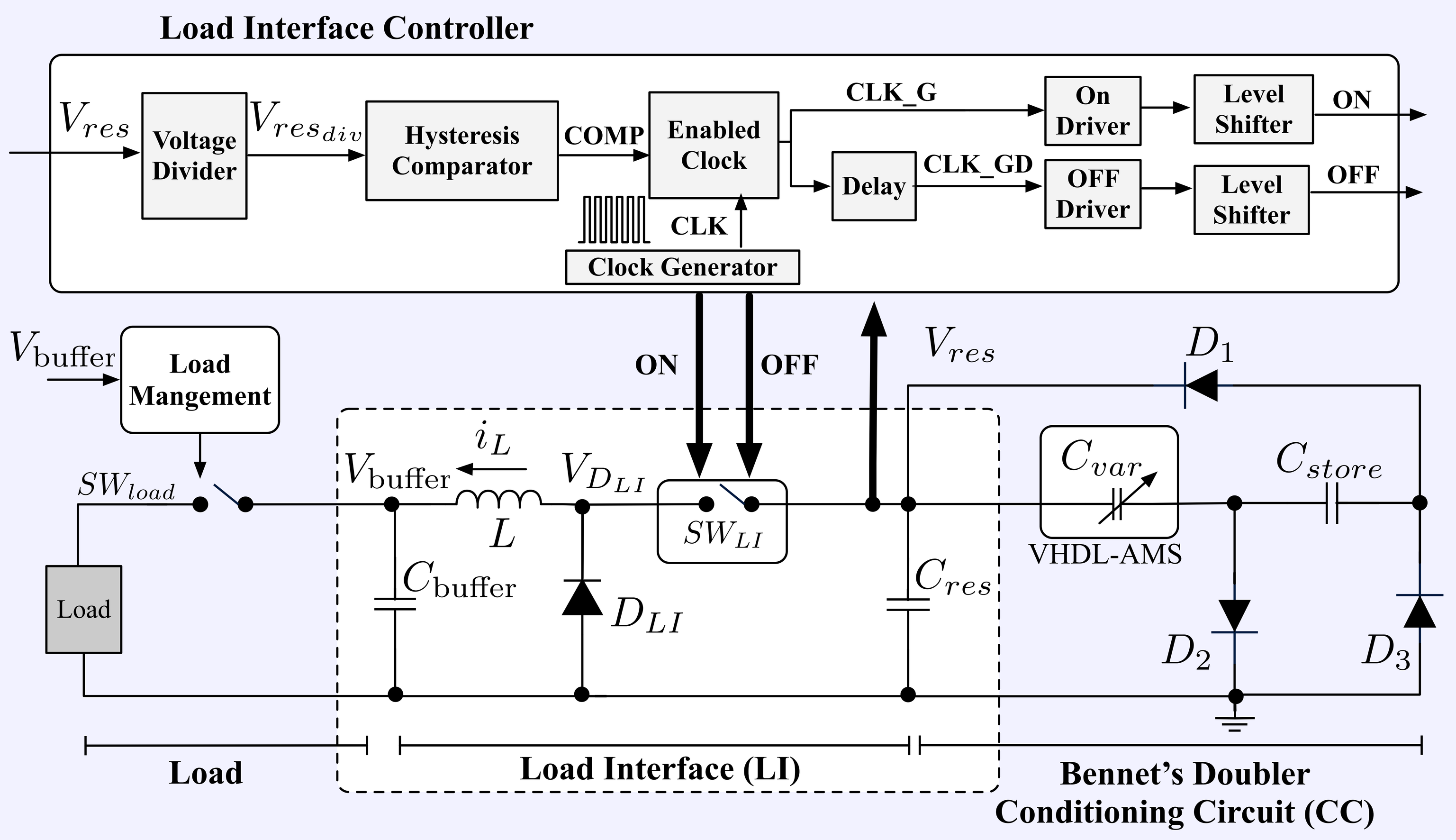

Figure 2: System block of the e-VEH incorporating Bennet's doubler CC, LI and LI Controller.

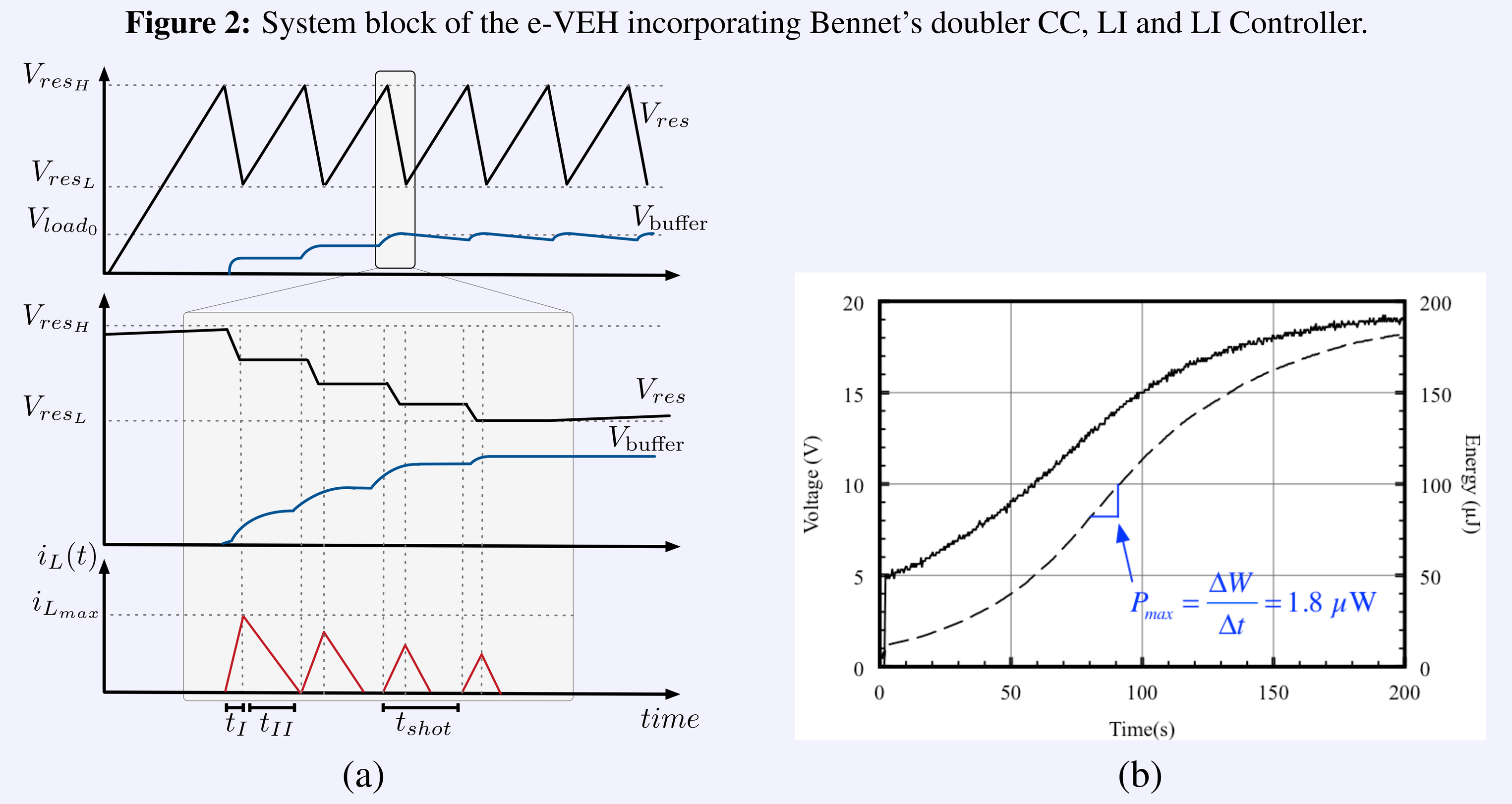

Figure 3: Evolution of V_{res} , V_{buffer} and i_L in multiple shot energy transfer (a). Energy harvested from a Bennet's Doubler CC [5] (b).

Load Interface Controller

- The LI transfers the energy using a switched inductor-capacitive architecture incorporating a high voltage switch designed in AMS0.35HV (50V option) [4].
- The LI requires 5 discrete components to operate, two capacitors one of which is a part of the harvester itself ($C_{res} = 1\mu F$ and $C_{\text{buffer}} = 20\mu F$), two resistances for the voltage divider and an inductor (15mH).
- The LI operates in multiple burst mode in order to minimize the current in the inductor.
- The LI control is achieved by sensing a downscaled voltage of C_{res} using a hysteresis comparator with predefined thresholds of $V_H = 10V$ and $V_L = 7.5V$.
- The switching signal is generated by an ultra low power clock generator inspired by [3].
- The average controller power is minimized thanks to an ultra low power RS-trigger comparator.

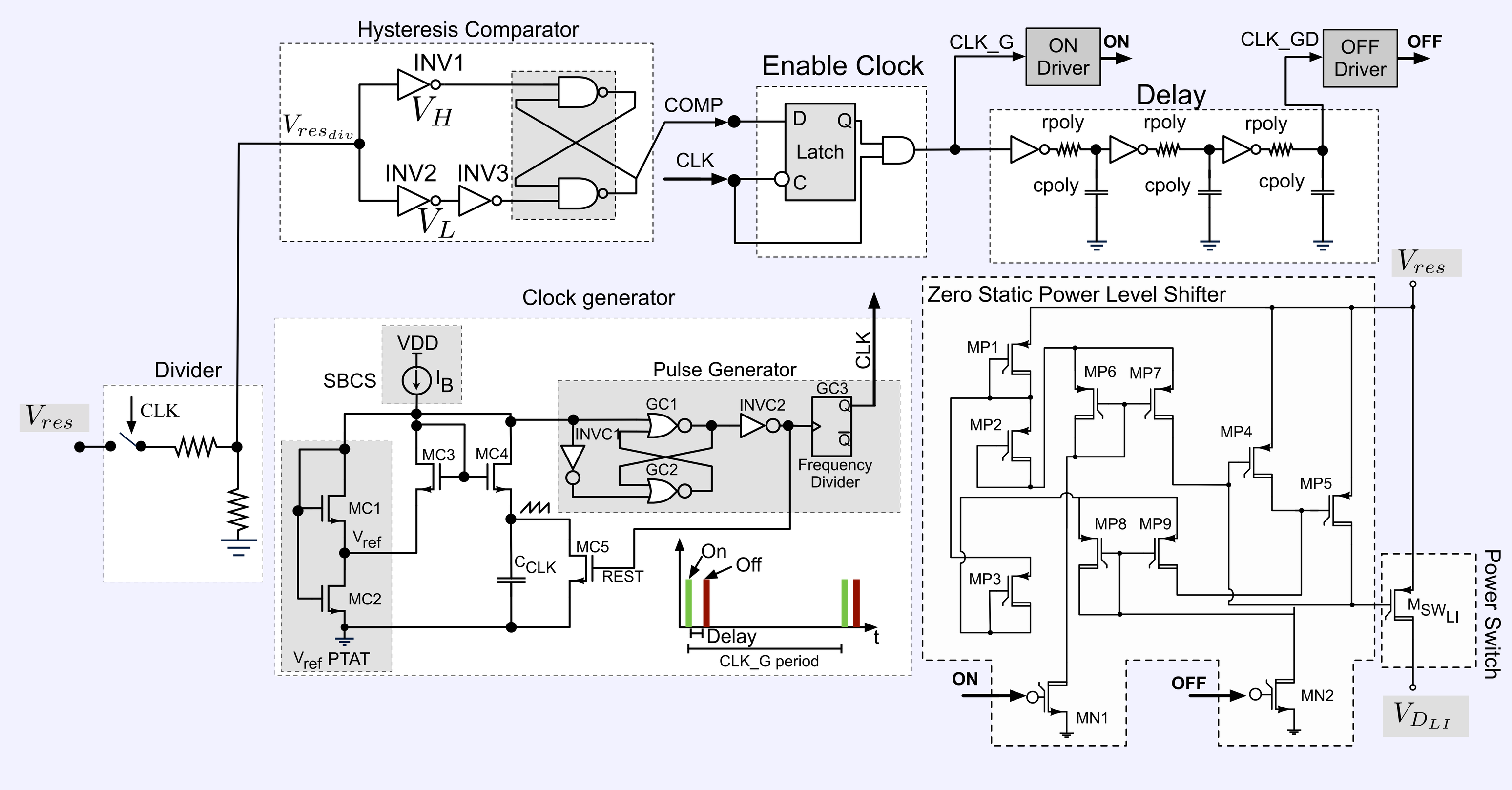

Figure 4: E-VEH Load Interface Controller

Results and Simulation

- A complete transistor level simulation shows that the LI controller average consumption power over 120sec is $< 100nW$ with table 1 summarising the energy consumption of each block.

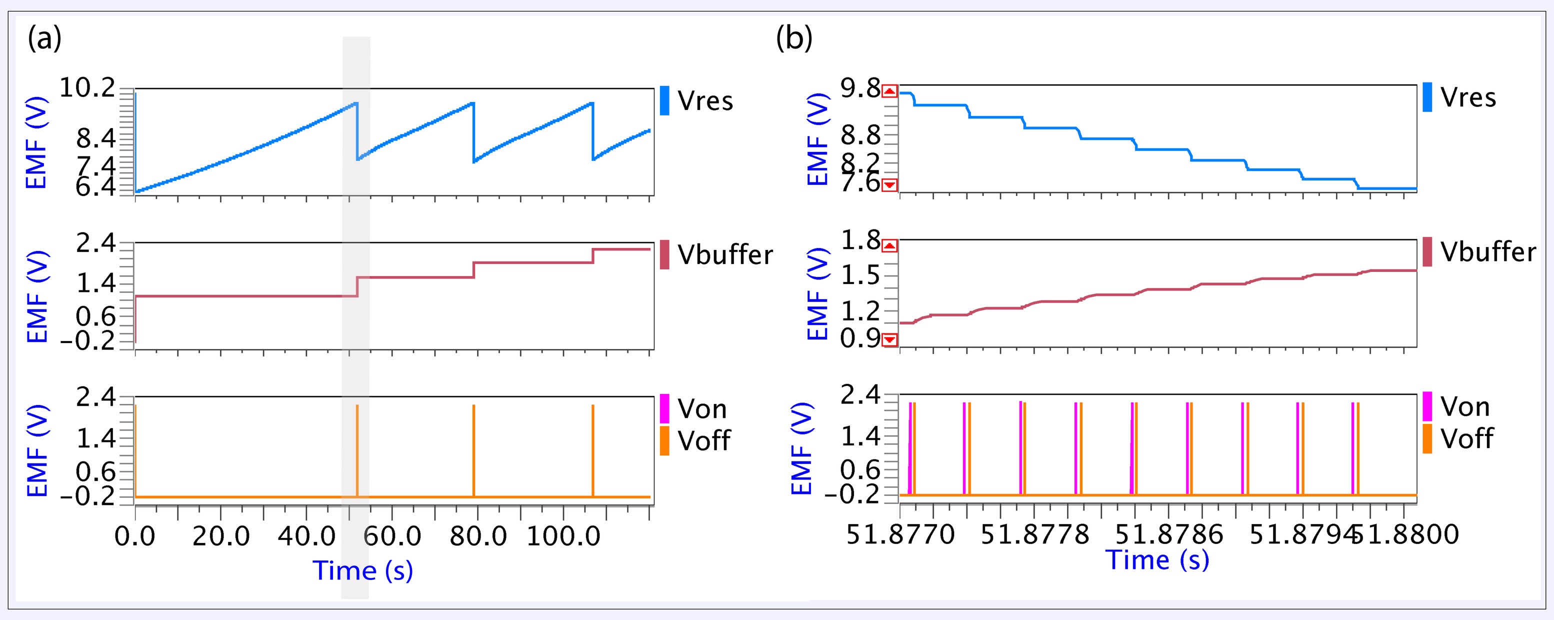

Figure 5: LI energy transfer for duration of 120s(a) and zoom in interval of $51.877s < t < 51.88s$ (b).

Block	Average Power
Clock generator	18.75nW
Hysteresis comparator	3.3nW
Delay	75nW
Gate Drivers	0.76nW
Level Shifters	0.24nW
Total	98.05

Table 1: Load Interface controller average consumed power.

Conclusion

- Low power LI is presented for e-VEH with multiple energy-shot controller.
- It mixes a high voltage interface with an ultra low power controller to maintain maximum harvested energy with overhead power consumed by LI controller of less than $100nW$.
- This work may be seen as a foundation stone for a smart and adaptive energy harvester, including automatic MPPT tracking which is still to be achieved for capacitive energy harvesters.

Practical Applications

Targeted applications for these kind of vibrational energy harvesting systems are autonomous low power fitness tracker and activity monitors. We believe it could enable these devices to work indefinitely without the need to recharge through an external energy source.

References

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