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# A Low-Power Microcontroller-Based Power Management Circuit with a two-measurements MPPT

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**Abstract**—This paper describes a low power implementation of a MPPT algorithm for weakly and moderately coupled piezoelectric energy harvesters (PEH). This “two-measurements” algorithm has been tested with the half-bridge SEH extraction technique (HB-SEH). Each time the input vibration frequency is modified, a microcontroller measures and generates an equivalent resistance at the optimal value ( $\pm 15\%$ ), which gives an input power larger than 95% of the maximum harvestable power. The first tests have shown that the proposed system and its MPPT consume only 7 $\mu$ A @ 1.8V with a STM32L011 microcontroller.

## I. INTRODUCTION

Vibration energy harvesting is a promising candidate for powering wireless sensor nodes for IoT. However, the power output of these harvesters heavily depends on the input mechanical conditions (vibrations amplitude and frequency) as well as the unavoidable harvester’s variations due to its aging or environment variation (temperature variation mainly). To convert vibration into electricity, piezoelectric-based harvesters are very attractive for their high power density at small scale [1] and their high output voltages as compared with electromagnetic converters. Piezoelectric energy harvesters (PEH) are classically qualified as weakly or strongly electromechanically coupled. This paper focuses on the weakly coupled PEH: Less efficient, but more common and cheaper than strongly coupled. Energy harvesting techniques are necessary to harvest the electrical power from the PEH. One classical technique is called Standard Energy harvesting (SEH) which is made of a full bridge rectifier and a rectifying capacitor. As the power extracted with this technique heavily depends on the output resistor of the PEH, Maximum Power Point Tracking (MPPT) algorithms must be implemented to harvest power for any input acceleration.

MPPT algorithms for weakly coupled algorithms can be divided in two categories: Perturb and Observe (P&O) and Open Circuit-Voltage (OCV) algorithms. The P&O algorithms continuously monitors the output power of the system and consequently adapts the output load of the harvester. These algorithms are often slow to reach their maximum power point [2]. OCV algorithms consists of measuring the open circuit voltage of the PEH, the maximum power is reached at half this open-circuit voltage in the case of SEH. There is no power transmitted to the load while the OCV algorithm is performed and a DC voltage must be regulated, which is not robust to acceleration amplitude changes [3]. Moreover, the displacement of the PEH in open-circuit is higher than when connected to a load, which can be limiting factor from a technological point of view.

In this paper, we propose a low-power implementation of two-measurements impedance estimation for weakly coupled PEH.

## II. MODEL AND METHOD

The PEH associated with the half-bridge SEH (HB-SEH) harvesting technique is also called voltage doubler [3]. This technique is similar to the SEH technique but with an optimal load equal to four times the one of SEH [4] in the case of weakly coupled PEH. In our case, the optimal load is emulated thanks to a flyback-type DC/DC converter. The discontinuous conduction mode control is adopted so that the emulated input resistance of the converter ( $R_{in}$ ) only depends on its switching frequency ( $f_{clock}$ ) and its duty cycle ( $t_{on} \times f_{clock}$ ) as given by Eq. (1) :

$$R_{in} = \frac{2L_p}{f_{clock} t_{on}^2} \quad (1)$$

with  $t_{on}$  the conduction time of the flyback primary side ( $K_p$  and  $L_p$ , as shown in FIGURE 1). A low-power microcontroller (a STM32L011 in our work) generates the control signal on  $K_p$ ’s gate. A low-power clock (100 kHz) feeds the microcontroller timer to create a fixed  $t_{on}$  PWM. We chose a fixed  $t_{on}$  control as it enables lower clock frequencies for the same range of emulated load [2], thus reducing power consumption. A schematic of the global system is shown in FIGURE 1.

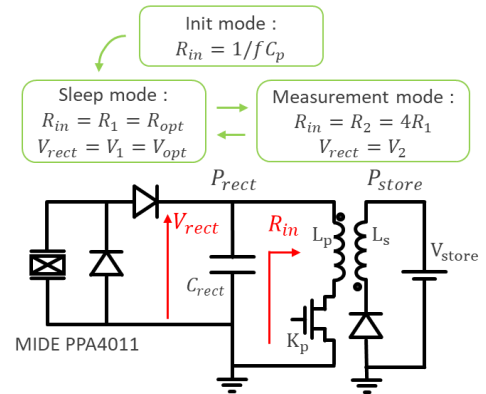


FIGURE 1 : ARCHITECTURE OF THE SYSTEM : MPPT FUNCTIONALITY AND HARVESTING TECHNIQUE

The two-measurements MPPT is based on [5] and similar to [6] insofar as it consists of a simplified impedance measurement. In this work, the measurement is performed with only two voltage measurements on capacitor  $C_{rect}$ . The two voltage measurements  $V_1$  and  $V_2$  are performed at two different emulated

loads ( $R_1, R_2$ ), allowing the calculation of an estimated optimal resistive load  $R_{opt-MPPT}$  thanks to Eq. (2).

$$R_{opt-MPPT} = \frac{(V_2 - V_1)R_1R_2}{V_1R_2 - VS_2R_1} \quad (2)$$

This method assumes that the PEH characteristic is linear for a given harvesting technique. In our case, the first emulated load  $R_1$  is assumed to be the optimal load of the system, calculated during the previous cycle of the MPPT algorithm.  $R_2$  is chosen relatively close to  $R_1$  to optimize the power extraction during the second measurement maintaining the operation of the system around the maximal power point.

### III. MEASUREMENTS

To validate our method, we used a MIDE PPA4011 with a 38 g (2 magnet disks of 25mm diameter x 5mm) inertial mass for the first experiments, set on an electromagnetic shaker driven to generate a sinusoidal acceleration whose amplitude is  $0.4 \text{ m.s}^{-2}$ . Its parasitic capacitance is approximately 400nF and the system's coupling is  $km^2 = 4\%$  ( $km^2Q = 1.6$ ). As a first approach, we set the first emulated resistance to  $R_1 = 1/(f_{piezo}C_p)$ , i.e the optimal load outside resonance for the HB-SEH technique, and  $R_2 = 4R_1$  for each frequency. For 35 input vibration frequencies (43 Hz to 50 Hz), the system automatically measures and generates an estimated optimal load ( $R_{opt-MPPT}$ ). For those tests, we measured the electrical powers before the flyback converter ( $P_{rect-MPPT}$ ) and the converted powers on the storage capacitor ( $P_{store-MPPT}$ ) at the flyback output (FIGURE 2). These power measurements were compared to those obtained with the optimal, manually found, discrete resistive loads ( $P_{opt-RES}$  @  $R_{opt-RES}$ ) connected to  $C_{rect}$  instead of our system. The estimated optimal loads ( $R_{opt-MPPT}$ ) are plotted and compared to the discrete optimal loads ( $R_{opt-RES}$ ) in FIGURE 3.

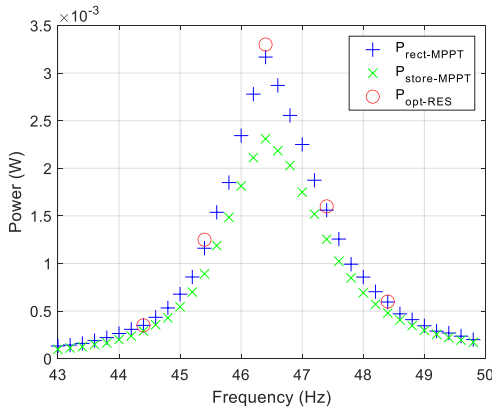


FIGURE 2 : ELECTRICAL POWERS OBTAINED WITH THE PROPOSED MPPT ( $P_{rect-MPPT}$  AND  $P_{store-MPPT}$ ) AT 0.4G COMPARED TO THE OPTIMAL POWER ON DISCRETE RESISTIVE LOADS ( $P_{opt-RES}$ )

We can see that the electrical powers upstream of the flyback are very close to  $P_{opt-RES}$ . It should be mentioned that the efficiency of the flyback (85% max - 73% min) has not been optimized yet. One can also note that the resistance values estimated by the algorithm follow the same trend and are relatively close to the discrete optimal loads. Further measurements are currently underway. It is complicated to see a

clear relationship between the optimal load  $R_{opt-RES}$  and the one obtained by the MPPT algorithm ( $R_{opt-MPPT}$ ) as the PEH for our experiment was weakly coupled and thus slightly impacted by load variations.

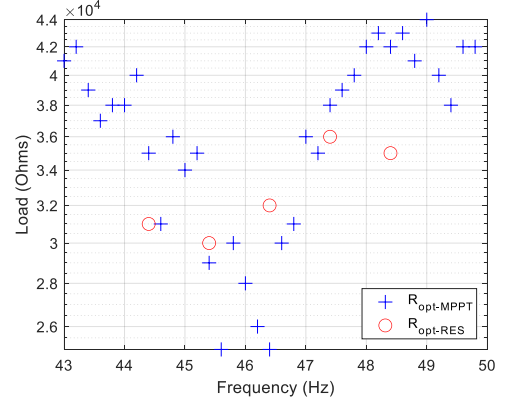


FIGURE 3 : OPTIMAL LOAD OBTAINED BY MPPT ( $R_{opt-MPPT}$ ) COMPARED TO THE OPTIMAL DISCRETE LOAD ( $R_{opt-RES}$ )

While emulating  $R_1$  and  $R_2$ , the microcontroller is in a deep-sleep state and consumes only  $2.5\mu\text{A}$  @  $1.8\text{V}$ . The voltage measurement is performed with a MOS commended voltage divider whose consumption is negligible over the whole system. The consumption of the 100kHz clock is of  $4.5\mu\text{A}$  @  $1.8\text{V}$  which give an overall estimated consumption of  $7\mu\text{A}$  @  $1.8\text{V}$  ( $12.6\mu\text{W}$ ) when connected to an external power supply.

### IV. CONCLUSION

This work shows the first results of a MPPT algorithm that applies a two-measurements method on a weakly coupled PEH while consuming only  $7\mu\text{A}$  (@  $1.8\text{V}$ ). The system continuously harvests energy and wakes up each time it changes from a measurement phase to a sleep phase where the optimal load is emulated. A next step would be to test this algorithm with a more coupled PEH so the impact of the load variation can be seen in more detail. It will also be used as the sub-block of a more complex system, addressing highly coupled energy harvesters.

### REFERENCES

- [1] S. Boisseau, P. Gasnier, M. Gallardo, and G. Despesse, "Self-starting power management circuits for piezoelectric and electret-based electrostatic mechanical energy harvesters," *Journal of Physics*, p. 6, 2013.
- [2] N. Kong and D. S. Ha, "Low-Power Design of a Self-powered Piezoelectric Energy Harvesting System With Maximum Power Point Tracking," *IEEE Transactions on Power Electronics*, vol. 27, no. 5, pp. 2298–2308, May 2012, doi: 10.1109/TPEL.2011.2172960.
- [3] B. Çiftci, S. Chamanian, A. Koyuncuoğlu, A. Muhtaroglu, and H. Kùlah, "A Low-Profile Autonomous Interface Circuit for Piezoelectric Micro-Power Generators," *IEEE Transactions on Circuits and Systems I: Regular Papers*, pp. 1–14, 2021, doi: 10.1109/TCSI.2021.3053503.
- [4] A. Brenes, A. Morel, J. Juillard, E. Lefeuvre, and A. Badel, "Maximum power point of piezoelectric energy harvesters: a review of optimality condition for electrical tuning," *Smart Mater. Struct.*, vol. 29, no. 3, p. 033001, Mar. 2020, doi: 10.1088/1361-665X/ab6484.
- [5] O. Freychet et al., "Efficient optimal load and maximum output power determination for linear vibration energy harvesters with a two-measurement characterization method," *Smart Mater. Struct.*, vol. 29, no. 1, p. 015003, Jan. 2020, doi: 10.1088/1361-665X/ab516f.
- [6] N. Decroix, P. Gasnier, and A. Badel, "An Efficient Maximum Power Point Tracking Architecture for Weakly Coupled Piezoelectric Harvesters based on the source I-V curve," in *2021 IEEE 20th International Conference on Micro and Nanotechnology for Power Generation and Energy Conversion Applications (PowerMEMS)*, Dec. 2021, pp. 136–139. doi: 10.1109/PowerMEMS4003.2021.9658370.