IDEC Chip Design Contest

# A 98% Tracking Efficient, 70 V/1.2 – 5 V Triboelectric Energy Harvesting Using Adaptively-Controlled Direct MPPT, Digitally-Controlled ZCS for IoT Applications


Seneke Chamith Chandrarathna, and Jong-Wook Lee

School of Electronics and Information, Kyung Hee University, jwlee@khu.ac.kr

Kyung Hee University WINS Laboratory


## I. INTRODUCTION

This poster presents a dynamically configured, high-voltage and ultra-low-power (ULP) DC-DC converter for triboelectric energy harvesting. The proposed converter IC, fabricated in a 180 nm high-voltage (HV) Bipolar-CMOS-DMOS(BCD) process, achieves input 48V/output (5V) conversion with an adaptively-controlled direct maximum power point tracking (ACD-MPPT) algorithm, which continuously tracks the input power by evaluating the input voltage and current. Through the dynamically configured interface circuit (DIC), the MPPT controller handles two triboelectric nanogenerators (TENGs) by optimally selecting either series or parallel configurations. The converter achieves tracking and end-to-end efficiencies of 98% and 88%, respectively, while consuming 416 nW at 5V output.

## II. DESCRIPTION

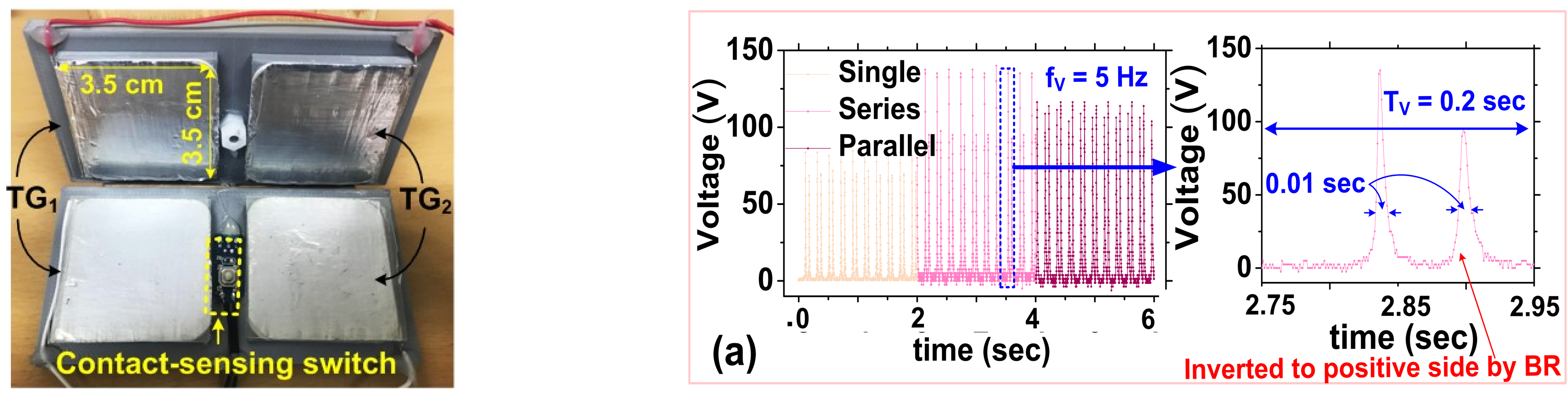


Fig. 1. Home-made TENG pair and the Measured TENG voltage as a function of time, and its extended waveform.

Fig. 1 shows the home made TEGN pair, which is assembled using Si-rubber and Aluminum (Al) as negative and positive materials, respectively. Note that: the open-circuit voltage of TENG only exists during a short-time [1] of 0.02 sec (excitation frequency: 5 Hz), which corresponds to around 10% of the excitation frequency.

1) Highly efficient MPPT controller is required to extract the power from TENGs
2) All controllers, including MPPT do not consume much power from TENGs

Fig. 2 shows the overall schematic of the proposed energy harvester, and it mainly consists of two TENGs, series to parallel/parallel to series (S/P) switch, an adaptively-controlled direct (ACD)-MPPT controller, a zero current sensing (ZCS) controller, voltage and current sensors.

1) ACD-MPPT controller: tracks the input power of TENG pair by directly measuring the input voltage and current
2) ZCS controller: blocks the negative current back to the system

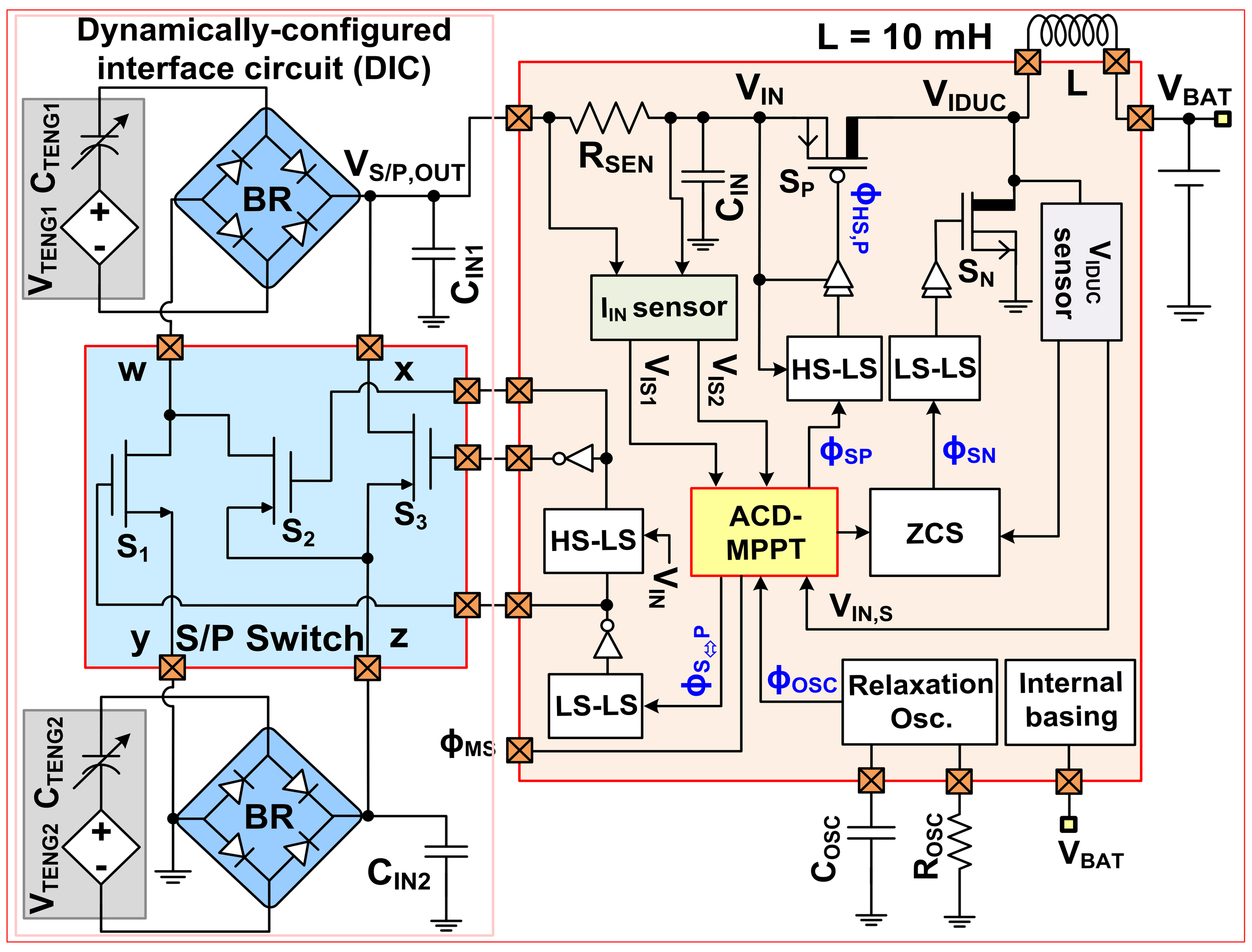


Fig. 2. Overall Architecture of the proposed system

As shown in Fig. 3, we implemented ACD-MPPT controller. Using the current and voltage sensors, we measured the scaled-down input current ($I_{IN}$) and voltage ($V_{IN}$), respectively.

1) $P_{IN}$-evaluator: determines the input power ($P_{IN}$) using $I_{IN}$ and $V_{IN}$
2) S/P controller: determine the configuration whether series or parallel of TENG pair
3) Input power comparison (IPC): compares the present input power ($P_{IN}$(n)) with its previous value ($P_{IN}$ (n-1))
4) Pulse delay controller (PDC): adjusts the on-time of power switch $S_P$ to control the input impedance of the buck converter

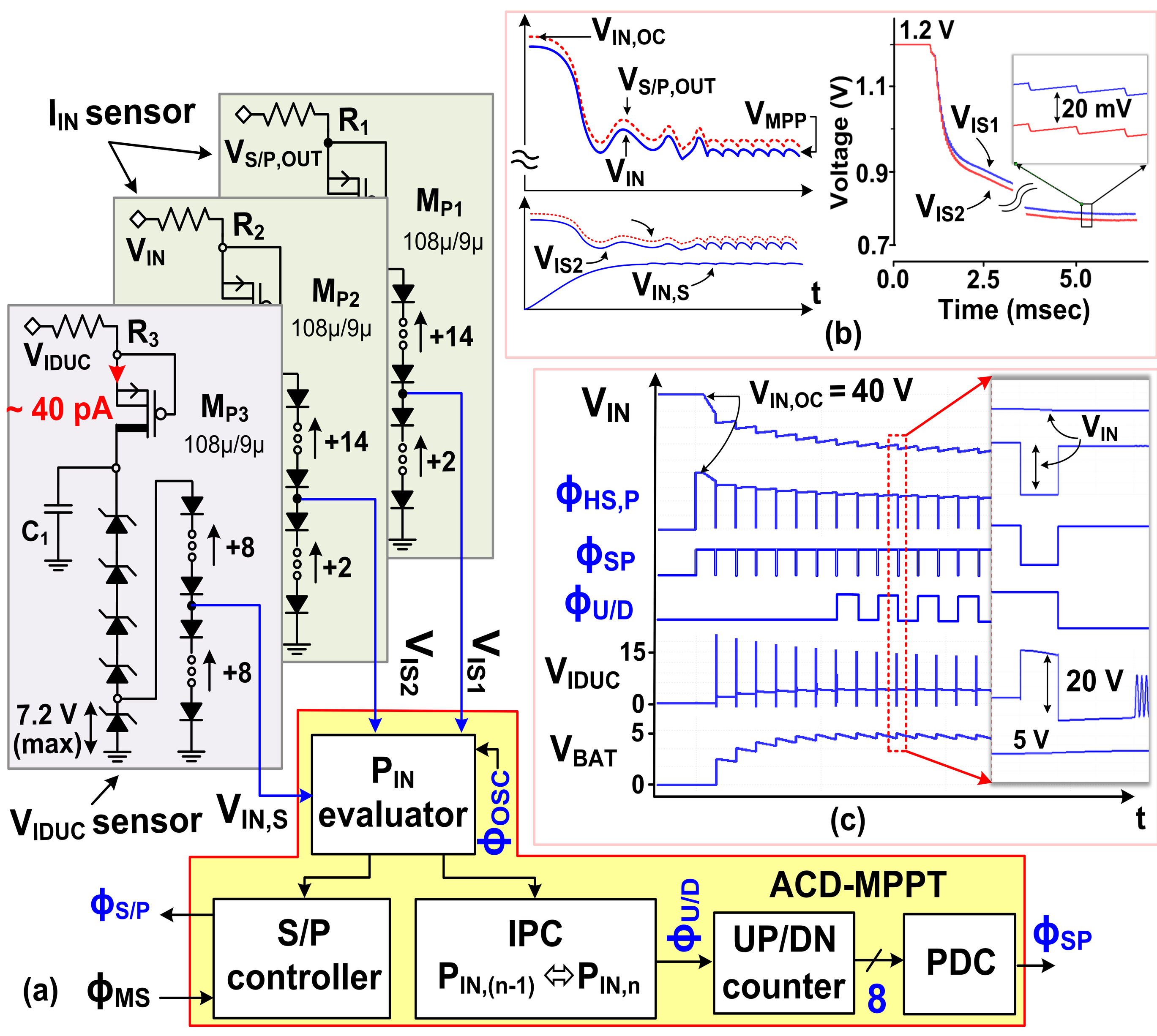


Fig. 3. Schematic of the ACD-MPPT controller.

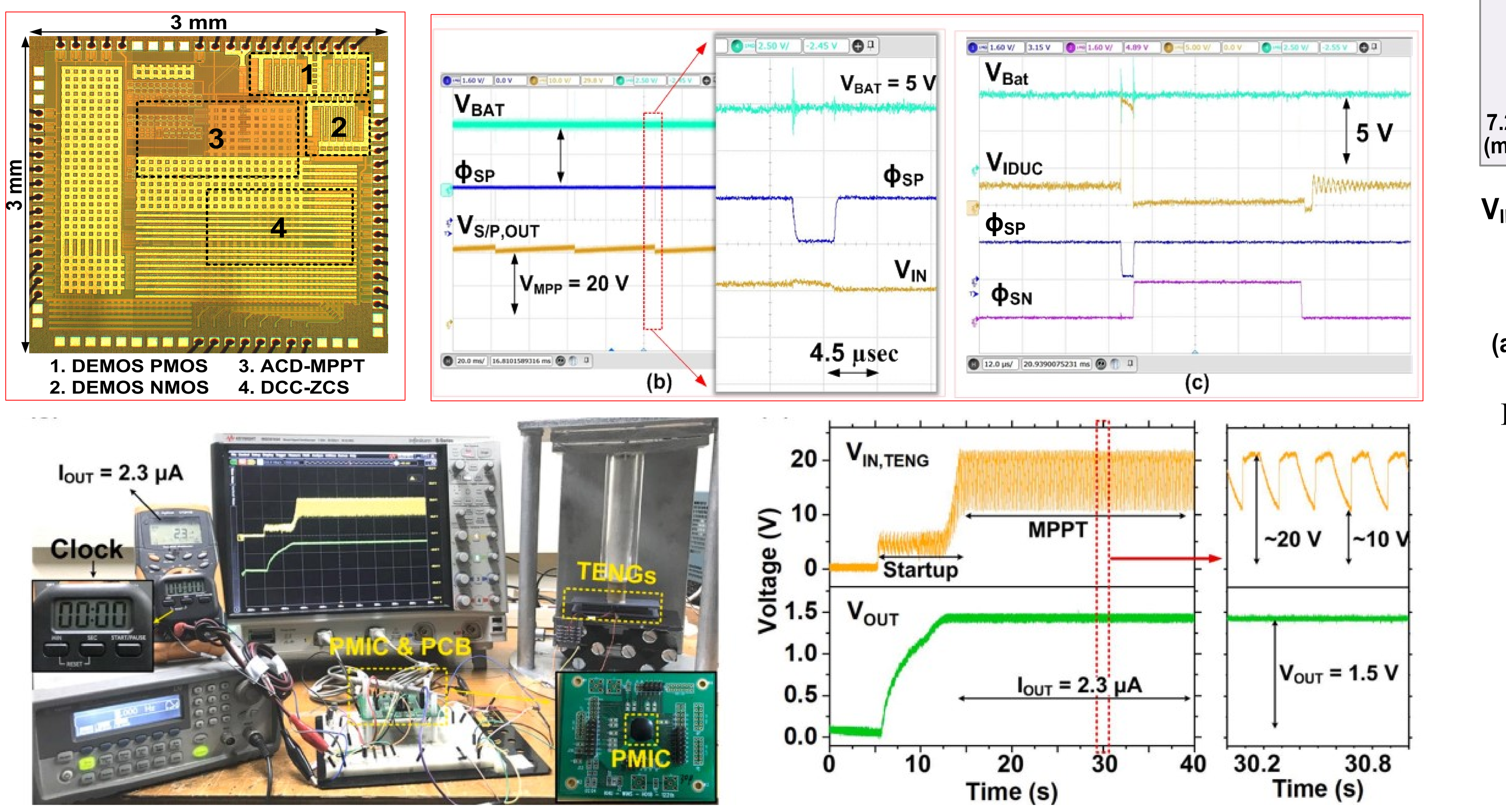


Fig .4. Die micrograph, measured waveforms of the MPPT and ZCS operation, experiment setup while powering a digital clock using proposed dc-dc converter and TENG pair, and the related waveforms.

As shown in Fig. 4, the proposed IC has area of 9 mm$^2$, Measured waveforms of the MPPT and ZCS controllers show the successful operation at the input of 20 V. To illustrate a practical approach, we power a digital clock using proposed dc-dc converter and TENG pair. The related waveforms show that the better MPPT operation while regulating the output at 1.5 V.

**Table. 1. Performance comparison**

| | [2] | [3] | [4] | [5] | This work |
|---|---|---|---|---|---|
| Process (nm) | 180 BCD HV | 350 BCD | 250 BCD | 180 BCD HV | 180 BCD HV |
| # of Sources | 1 | 1 | 1 | 1† | 2 |
| Connection type | Master-slave | - | - | - | Series ⇔ Parallel |
| Source type | Ideal | Piezo electric | Electro static | Tribo electric | Tribo electric |
| $V_{S,peak}$††(V)/ $V_{IN}$ (V) | 48/48 | 7/7 | 60/60 | 70/70 | 100/ 48 |
| $P_{IN}$ min | - | 33 µW | 1 µW | 4.5 µW | 0.8 µW |
| $V_{OUT}$ | 1 V Regulated | 1 – 8 V | 1 – 5 V | 1 – 5 V | 5 V Regulated |
| Tracking Parameters | $I_{OUT}$ | $V_{IN,OC}$ | $I_{OUT}$ | $V_{IN,OC}$ | $V_{IN}$, $I_{IN}$ |
| Power consumption | - | 10 µW | 500 nW | - | 416 nW |
| $\eta_{MPPT}$ | - | 99 % | 99 % | 97 % | 98 % @ 74.6 µW of $P_{IN}$ |
| $\eta_{EE}$ | - | - | 85 % | - | 88 % @ 4 MΩ of $R_{TENG}$ |
| $\eta_{CONV}$ | 85.4% | 80 % | - | 51.1 % | 86.2 % |

†Dual inputs using a single TENG ††Peak amplitude of the input source

**Conclusion** of the proposed work can be further discussed using the above comparison Table. 1, it shows several advantages, including S/P configuration, very low power consumption, and favorable efficiency performances.

## References


[1] J. Peng, et al., Sci. Adv, Dec. 2017.
[2] D. Yan, et al., IEEE Symp. VLSI Circuits, Dig. Tech. Pap. 2019.
[3] Y. Song, C. H. Chan, Y. Zhu, L. Geng, S. P. U and R. P. Martins, “Passive noise
[3] M. Shim, et al., J. Solid-State Circuit, Oct. 2011.
[4] S. Stanzione, et al., ISSCC Dig. Tech. Papers, 2015.
[5] I. Park, et al., ISSCC Dig. Tech. Papers, 2018.


## Acknowledgement


The chip fabrication and CAD tools were supported by the IDEC (IC Design Education Center).