IDEC Chip Design Contest

A High Voltage DC-DC Buck Converter with MPPT for Triboelectric Nanogenerator (TENG) Energy Harvesting

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Introduction

Triboelectric nanogenerators (TENGs) are lightweight, low-cost devices ideal for harvesting mechanical energy from sources like human motions. However, their high-voltage, low-power pulse output and high source impedance limit practical energy extraction. This work presents a compact Energy Harvester Interface IC (EHI-IC) featuring a high-voltage DC-DC buck converter and a dual-parameter MPPT algorithm, fabricated in 180nm BCD technology. The design enables efficient energy conversion from high-impedance TENGs, achieving up to 95.5% tracking efficiency, and delivers a stable DC output, unlocking reliable power for self-powered IoT and marine systems.

System Architecture

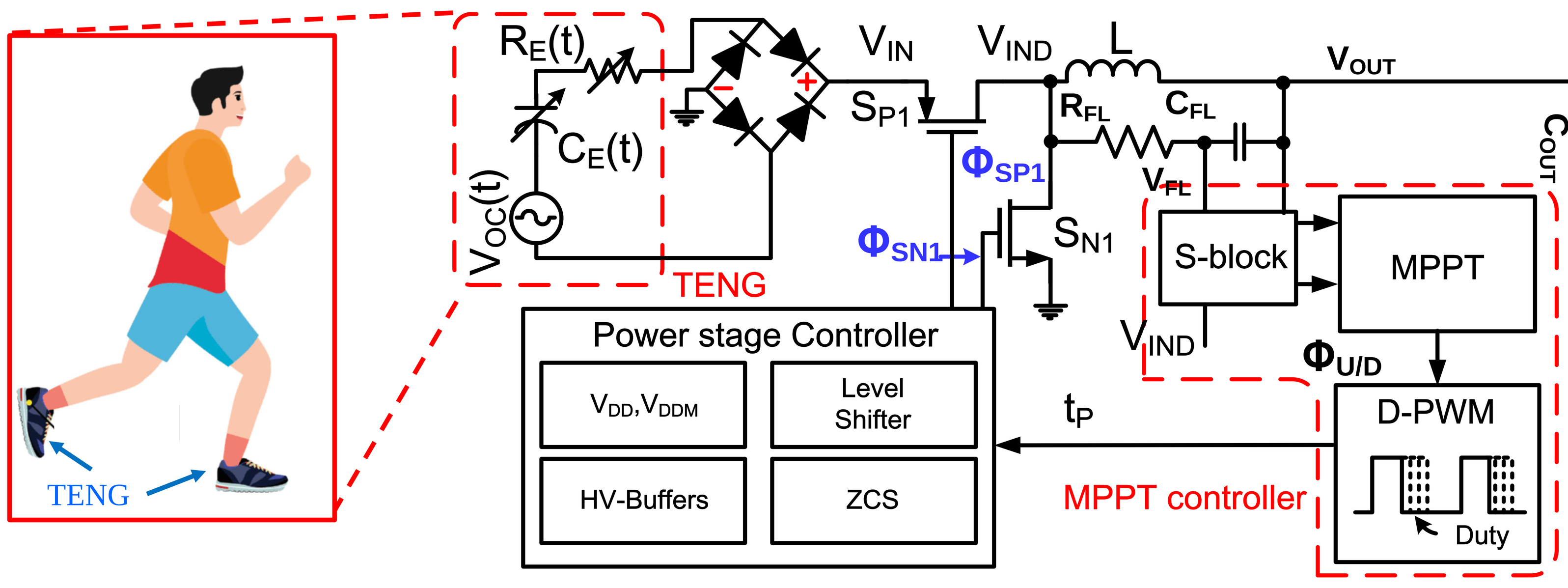


Fig. 1. Block diagram of proposed HV dc-dc buck converter.

Key Innovations

- Power-to-Bit Converter (PBC): Digitizes analog power levels for MPPT decision-making
- Asymmetric Capacitive Level Shifters: Ensure ultra-low-power voltage translation
- Dual-parameter MPPT: Tracks both voltage and current for optimized performance

MPPT controller

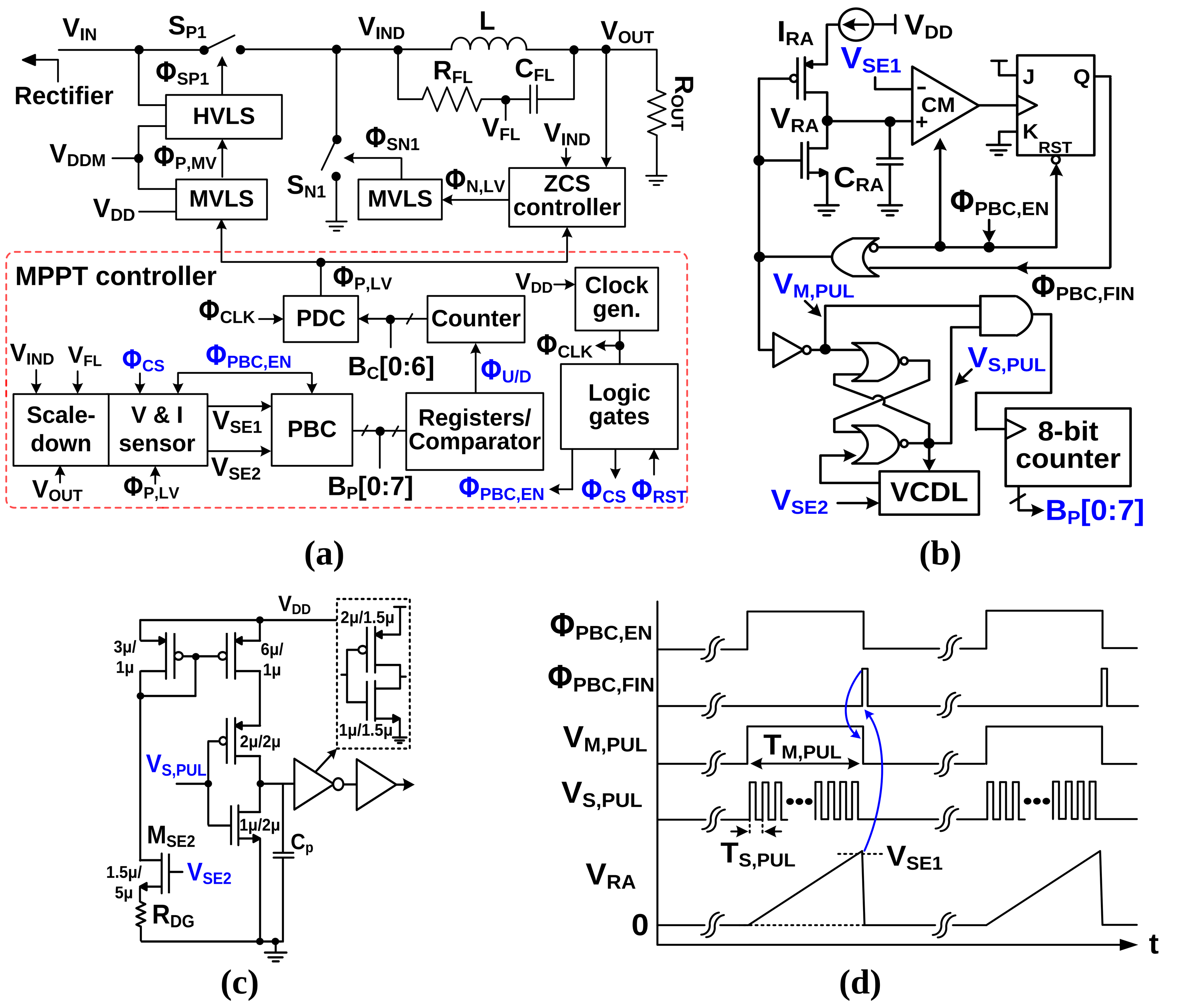


Fig. 2(a) Block diagram of proposed MPPT controller, (b) schematic of the PBC, (c) voltage-controlled delay line, (d) Operational waveforms of the PBC.

$$T_{S,PUL} \cong 2\left(\tau_{NOR} + \tau_{VCDL}\right) \qquad B_p[0:7] = \left[\frac{T_{M,PUL}}{T_{S,PUL}} - 0.5\right]$$

- **Digital Power Tracking**

The PBC generates an 8-bit digital value representing input power by multiplying scaled voltage (VSE1) and current (VSE2). A feedback loop continuously tunes the duty cycle (t_p) via ΦU/D signals to stay at the optimal power point.

- **Efficiency Boost with ZCS**

The Zero-Current Sensing (ZCS) controller detects the exact moment when inductor current hits zero, avoiding energy loss from reverse currents and enabling precise switch control.

Simulation Results

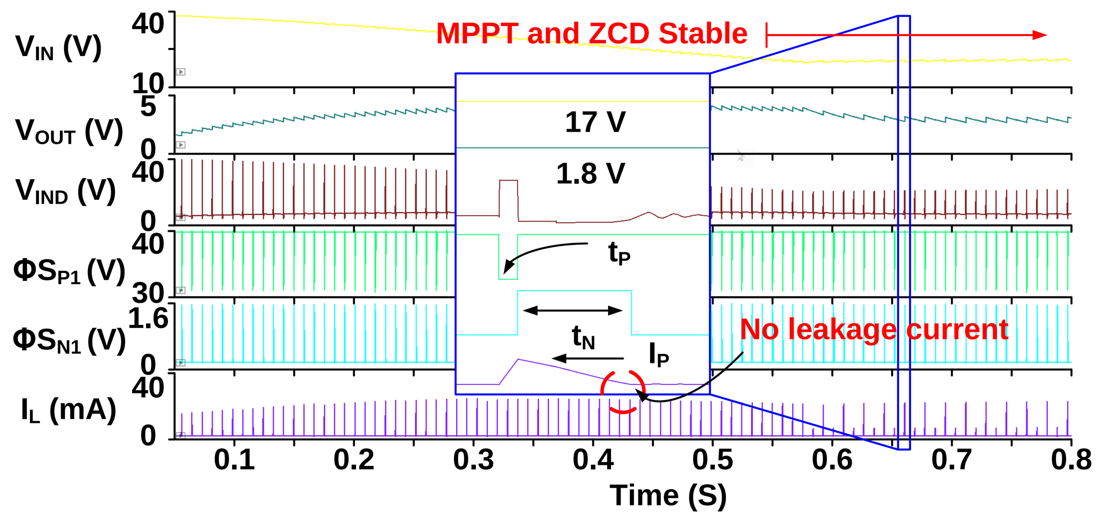
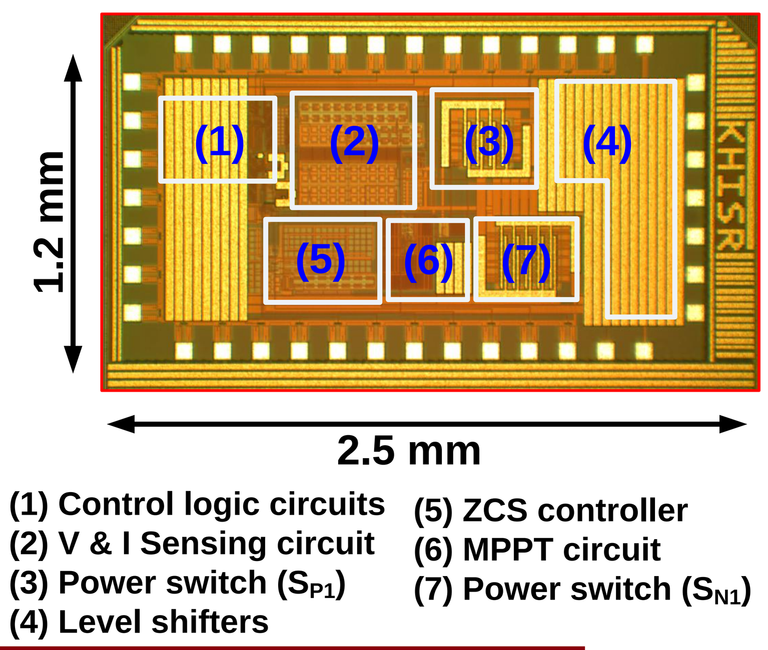


Fig 3. Simulated overall performance of the EHI-IC.

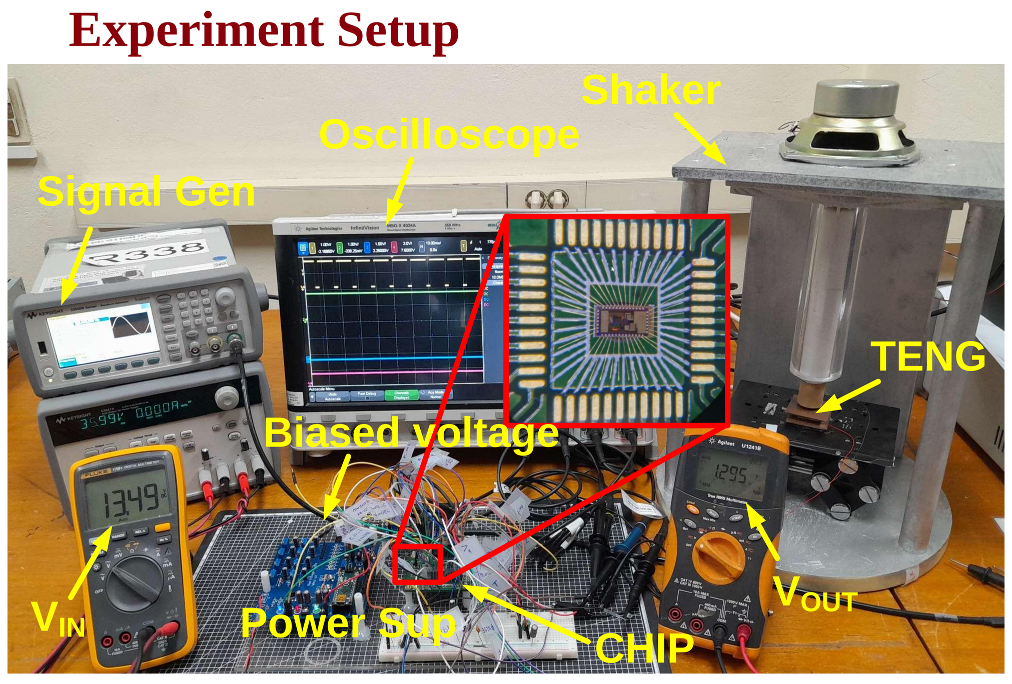
The EHI-IC demonstrates efficient energy extraction from a TENG with an initial open-circuit voltage (VOC) of 36 V. During MPPT operation, the input voltage (VIN) stabilizes at 17 V, while the output voltage remains steady at 1.8 V.

ZCS controller ensures precise switch timing, eliminating reverse current. These results confirm the EHI-IC's capability to achieve optimal energy conversion from high-impedance sources.

Chip Micrograph



Experiment Setup



Experiment Results

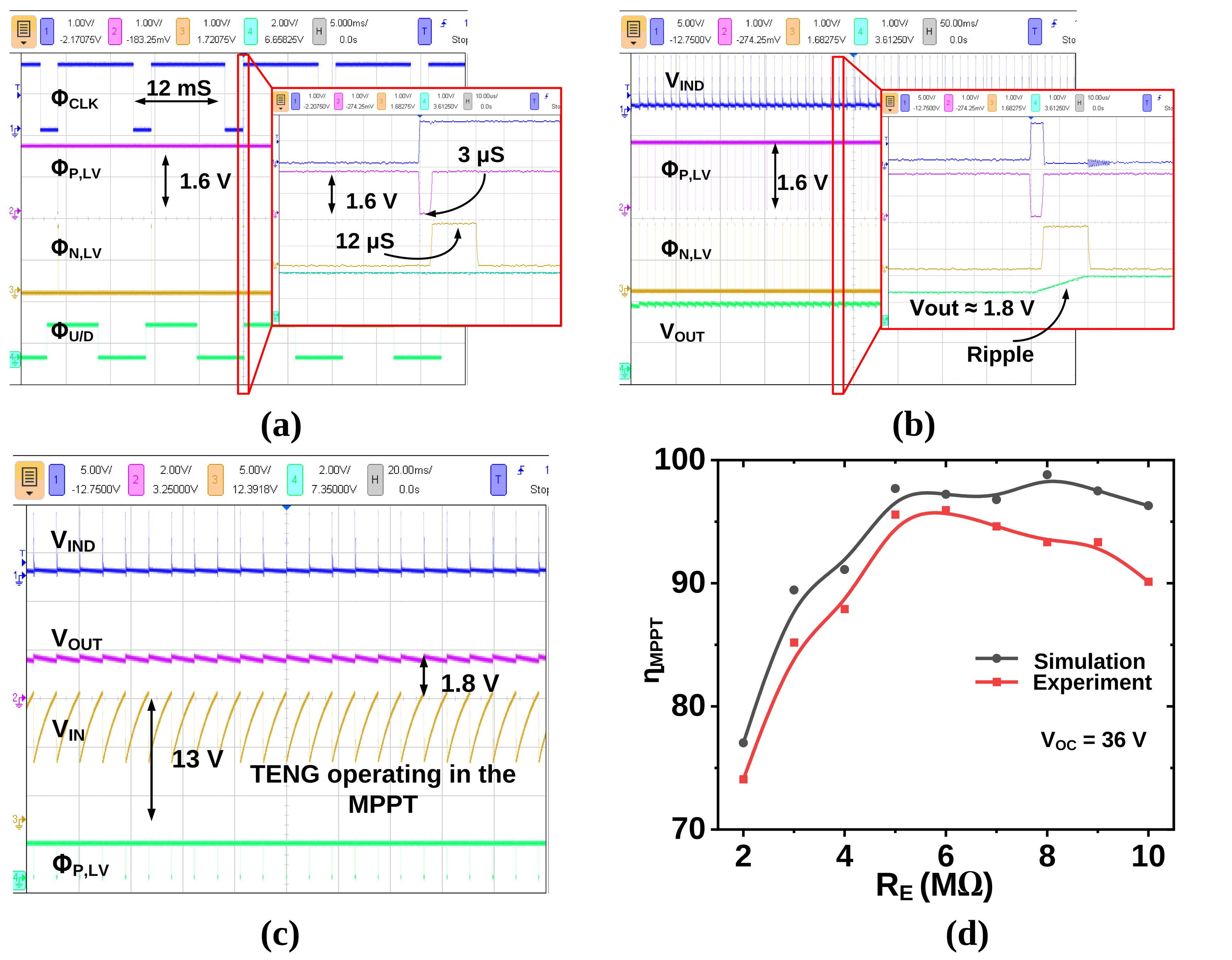


Fig. 4 Measured waveforms of the oscillator and MPPT controlling circuit, (b) inductor voltage (c) overall performance of the EHI-IC, (d) Tracking efficiencies as a function of the R_E . V_{OC} = 36 V, R_{OUT} = 100 KΩ.

Measured waveforms confirm stable 1.8 V output and effective MPPT operation. The controller dynamically adjusts the duty cycle, while zero-current switching ensures efficient inductor discharge. The EHI-IC consistently extracts energy from a 36 V TENG source, demonstrating robust and reliable performance.

Conclusion

A compact EHI-IC was successfully designed and validated for efficient power extraction from high-impedance TENGs. Integrating a high-voltage buck converter with MPPT and ZCS control, the system achieved up to 95.5% tracking efficiency. Fabricated in 180nm BCD, the IC demonstrates stable and reliable performance, paving the way for future self-powered IoT and marine energy applications.

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