IDEC Chip Design Contest

An Efficient Multimode Boost Converter Using Adaptive MPPT with Resonance Frequency Generator for TEG Energy Harvesting

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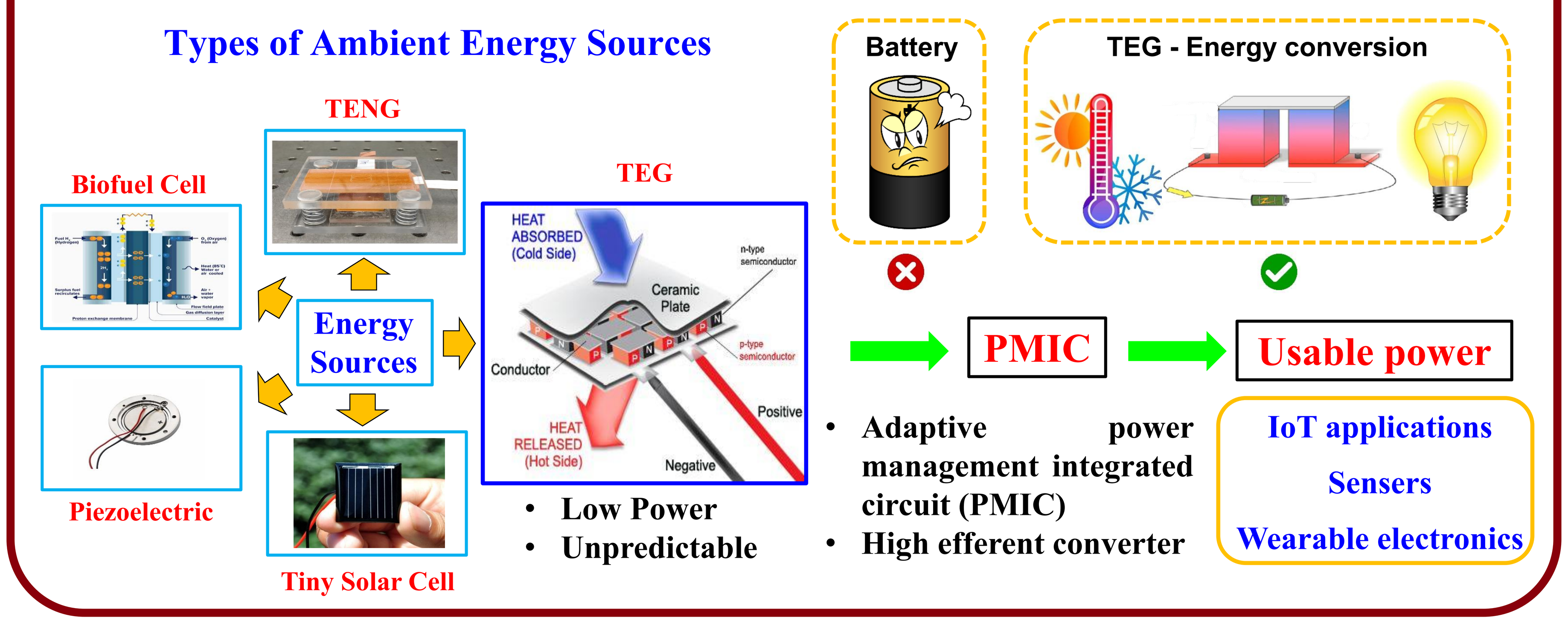
Introduction

- Energy harvesting is the process of capturing and converting ambient energy from various sources into usable electrical power.
- This technology enables devices to operate without traditional power sources, Batteries or wired electricity by utilizing ambient energy sources for applications.



Challenges and Proposed Objectives

Challenges

- Wide variation in source resistance (R_S) leads to severe impedance mismatch.
- Conventional converters operate in a single conduction mode, limiting efficiency over varying conditions.
- In practice
  - DCM → low switching loss but high conduction loss
  - CCM → low conduction loss but high switching loss
- Fixed-frequency (f) operation fails to adapt between CCM, CRM, and DCM, resulting in suboptimal maximum power point tracking (MPPT) performance.

CCM – continuous conduction mode, CRM – critical conduction mode , DCM – discontinuous conduction mode.

Design Objectives

- Enable automatic multimode operation (CCM / CRM / DCM) based on input conditions.
- Achieve optimal loss trade-off
  - DCM → low-power operation
  - CCM → high-power operation
  - CRM → efficient transition (Transition mode)
- Provide adaptive impedance matching across wide R_S variation.

PMIC Circuit Implementation

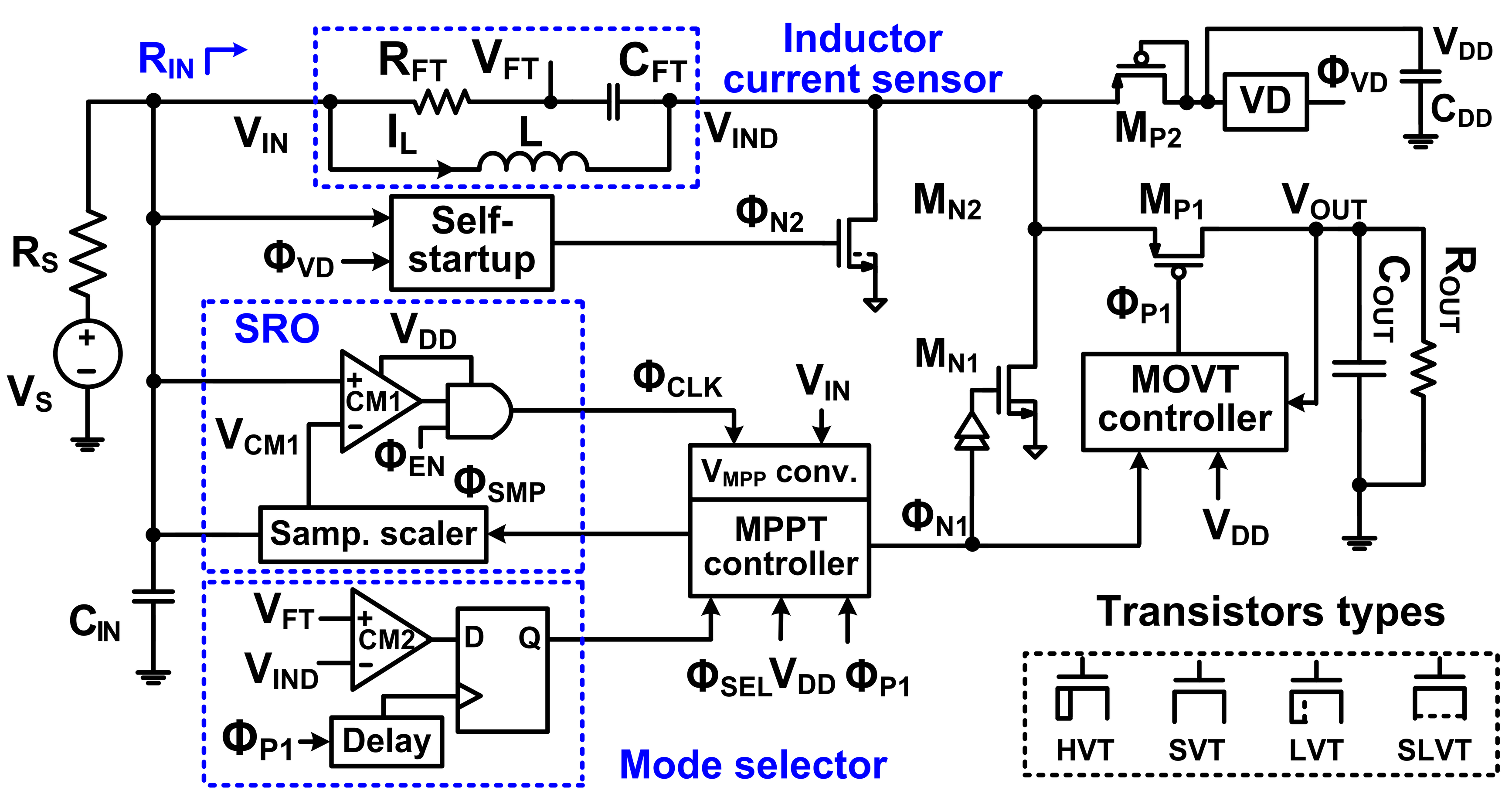


Fig. 1. Block diagram of the PMIC.

- Self-resonant oscillator (SRO) generates variable f according to the voltage source (V_S) and R_S variation.
- Inductor current sensor and path selector determine the operating mode of the converter using the selector signal Φ_{SEL}.

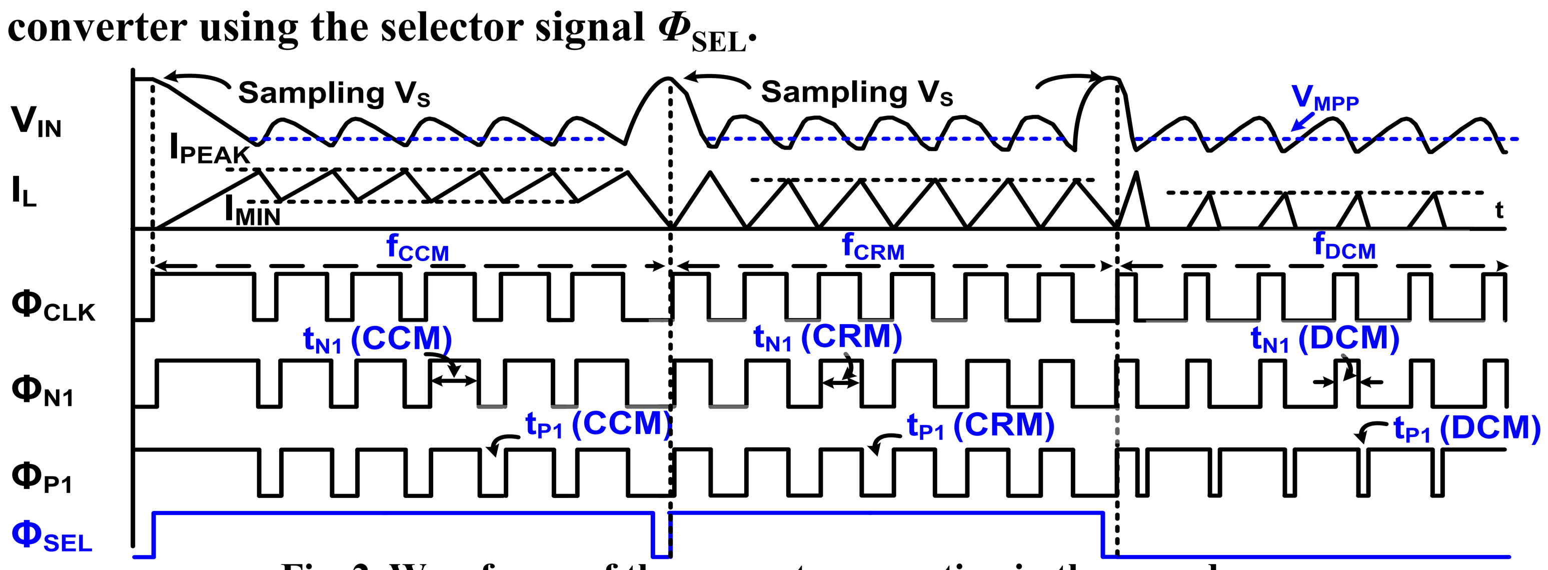


Fig. 2. Waveforms of the converter operating in three modes.

Simulated MPPT with Mode Changers

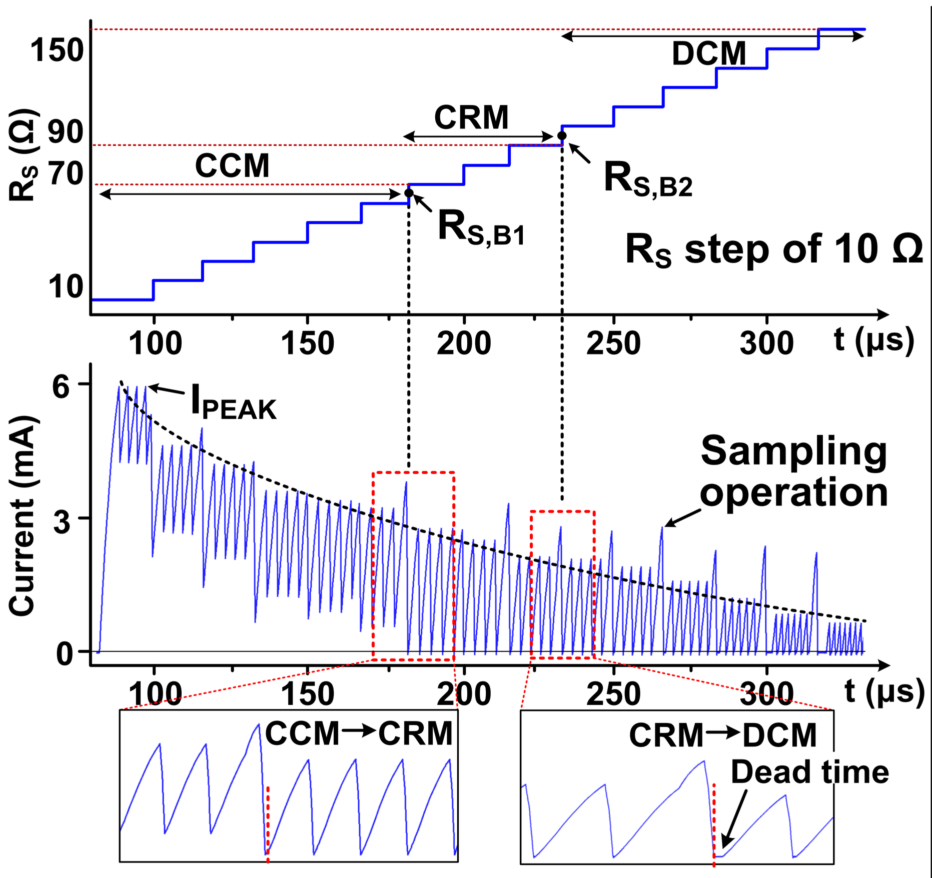


Fig. 3. Simulated inductor current waveforms and mode change when R_S is gradually increased. V_S = 150 mV, L = 1 mH, and R_{OUT} = 300 kΩ

$$f_{CCM} = \frac{1}{t_{N1}+t_{P1}} = \frac{R_S}{2L}\frac{V_S}{(2I_{PEAK}R_S - V_S)}\left(1-\frac{1}{\beta}\right) \quad (1)$$

$$f_{CRM} = \frac{1}{t_{N1}+t_{P1}} = \frac{1}{t_{N1}(1+1/(\beta-1))} = \frac{R_S}{2L}\left(1-\frac{1}{\beta}\right) \quad (2)$$

$$f_{DCM} \cong \frac{V_S^2}{2L\cdot I_{PEAK}^2 R_S}\left(\frac{\beta-1}{\beta}\right) \quad (3)$$

$$I_{PEAK} = \frac{V_{S0}}{(R_S)^{n0}}\,[\mathrm{mA}] \quad (4)$$

Using (1), (2), and (4), we solve for $R_{S,B1}$, which can be expressed as

$$R_{S,B1} = \frac{V_S}{I_{PEAK}} \cong \left(\frac{V_S}{V_{S0}}\right)^{1/(1-n0)} \quad (5)$$

Similarly, we obtain $R_{S,B2}$ using (2), (3), and (4), as

$$R_{S,B2} = \frac{V_S}{I_{PEAK}}\sqrt{\frac{2}{2-(V_S/V_{OUT})}} = R_{S,B1}\left(\frac{1}{\sqrt{1-(1/\beta)}}\right)^{1/(1-n0)} \quad (6)$$

where $\beta = V_{OUT}/V_S$, and V_{OUT} is the output voltage, V_{S0} and $n0$ are fitting parameters. For V_S = 120, 140,200 mV, we obtain V_{S0} values of 9.34, 17.1, and 44.1, respectively, and $n0$ values of 0.47, 0.54, and 0.62, respectively.

Chip Micrograph and Experiment Setup

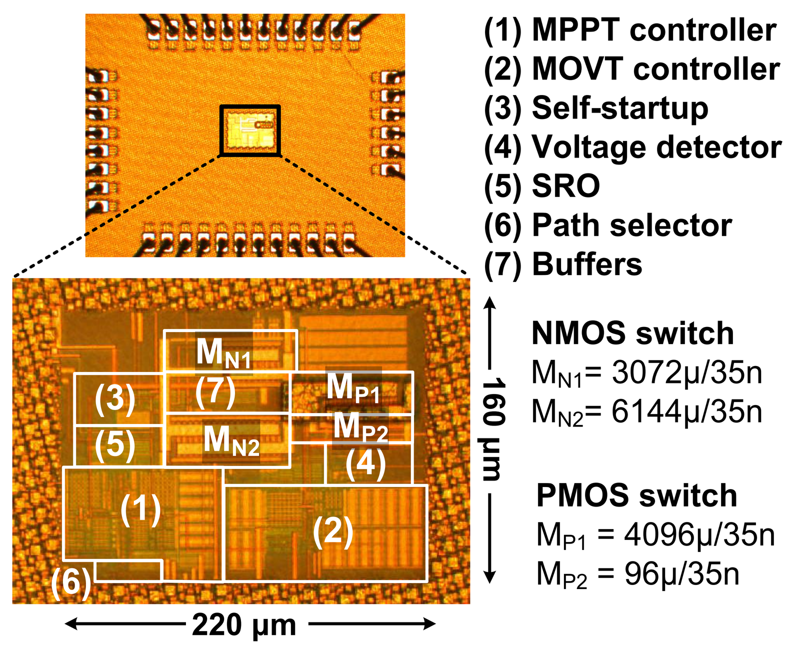


Fig. 4. Micrograph of the fabricated PMIC

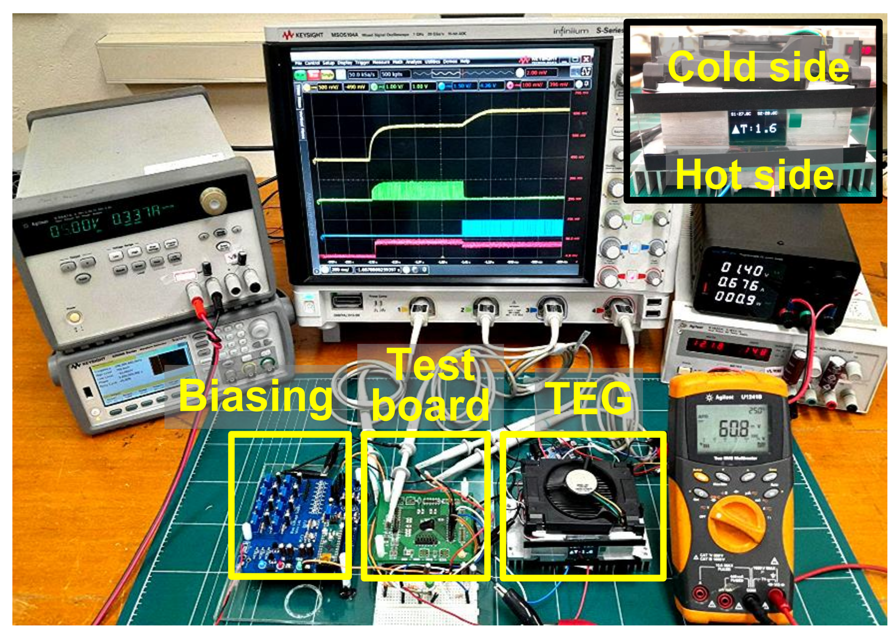


Fig. 5. Experimental setup for PMIC with a commercial TEG

Measurement Results

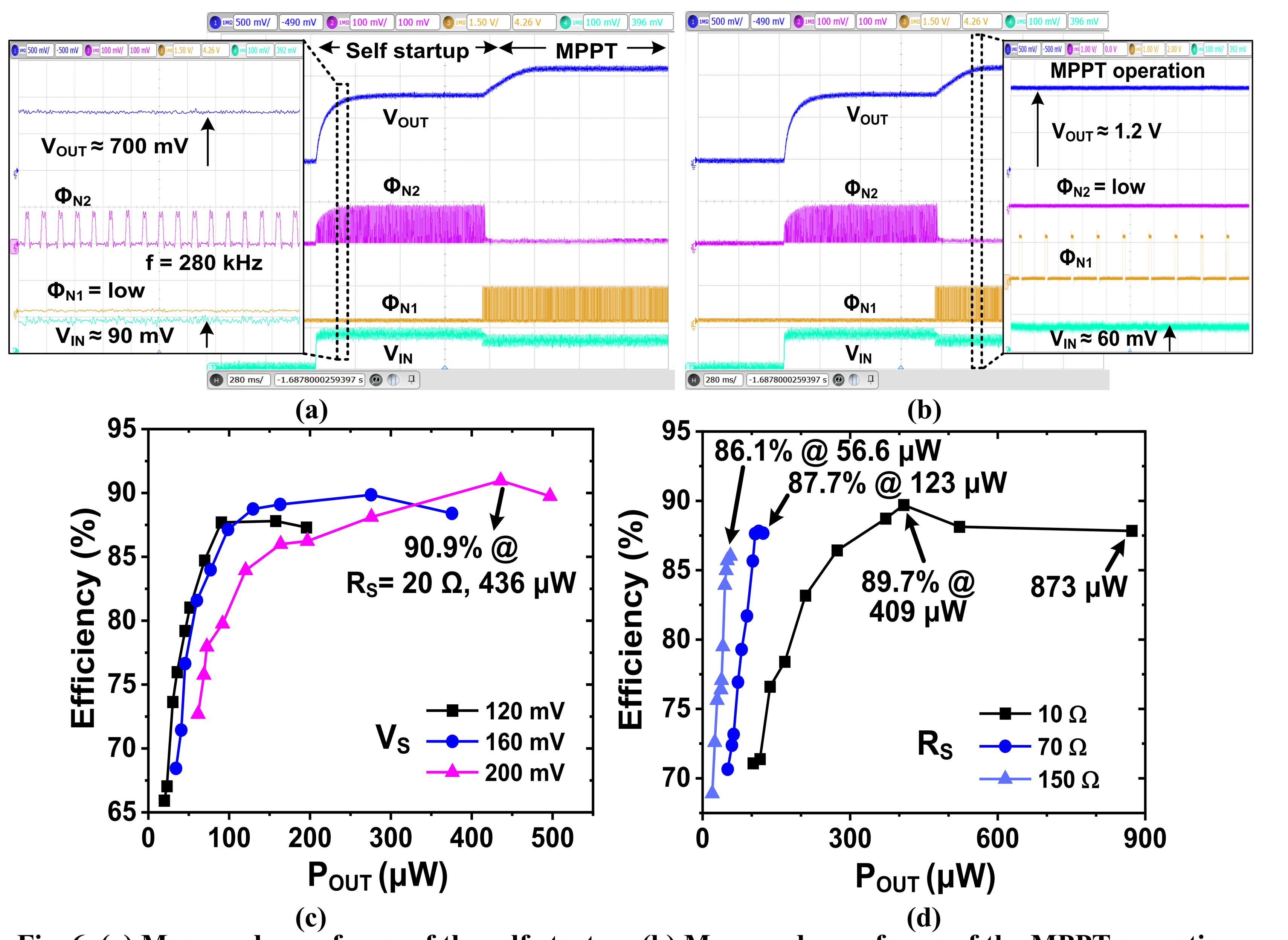


Fig. 6. (a) Measured waveforms of the self-startup, (b) Measured waveforms of the MPPT operation, measured conversion efficiency as a function of P_{OUT} using different (c) V_S and (d) R_S values.

Conclusion

- The SRO with a power converter embedded MPPT is presented for TEG energy harvesting. By enabling automatic multimode operation (CCM/CRM/DCM), the proposed design achieves wide-range impedance tracking and maintains high efficiency under varying V_S and R_S conditions.
- This validates the effectiveness of self-resonant MPPT for next-generation energy harvesting systems.

Acknowledgement

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