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Thermal energy harvesting circuit with maximum power point tracking control for self-powered sensor node applications

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Key words: Thermoelectric energy; Energy harvesting; Maximum power point tracking (MPPT) control; Self-powered system; Sensor node

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Motivation

- Commonly used TEG devices can generate low output voltages 10–50 mV/K. Therefore, a boost converter is needed to provide the output voltage required for powering electronic devices and the focus has been on start-up and DC-DC boosting issues.
- Several start-up techniques have been reported using pre-charged batteries, mechanical switches, off-chip transformers, LC oscillators, or post-fabrication processes.
- These techniques are not applicable to battery-free self-powered sensor nodes or are not suitable for system integration/miniaturization.

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Main idea

- Recently, TEG devices with high output voltages have been developed. A commercial TEG device can generate nearly 6 V of open voltage ΔT less than 5 °C. With the high-voltage TEG devices, start-up and DC-DC boosting issues can be solved. Using these devices, the main remaining design issue is the MPPT capability.
- A simple implementation technique for a thermal energy harvesting circuit designed for TEG devices with high output voltage is presented. No complex start-up circuitry is required. A simple MPPT controller using the FOC technique is proposed to extract as much power as possible from the TEG device

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Method

1. Operates in active/asleep mode where the application load switches between active and asleep modes depending on the harvested energy.
2. Pulse generator is designed to generate an MPPT pulse for MPPT control that is one cycle long for every 128 cycles of the clock signal from a ring-type oscillator .
3. A two-stage sample and hold architecture is employed to reduce leakage and to maintain the sampled MPP voltage during the long hold times.
4. To track the MPP, load matching is achieved by adaptively connecting the storage capacitor to the load

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Major results

- The measured peak power efficiency is 95.5%.
- The power conversion efficiencies are greater than 87% for 500 Ω $\leq R_{Load} \leq$ 15 kΩ.
- The MPP tracking accuracy is greater than 99%.

Parameter	This work
Process	0.35 μm CMOS
TEG	R_T = 15 kΩ
Vin [*: V_{OC}]	*2V–5V
Vout (V)	1–2.5
Required external voltage	None

Parameter	This work
No. of inductors	0
MPPT scheme	FOC
MPPT tracking accuracy	99%
Peak Efficiency (end-to-end)	97.5%
Active Area (mm^2)	0.43

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Conclusions

- A simple thermal energy harvesting circuit designed for TEG devices with high output voltage is proposed.
- The circuit operates in active/asleep mode and includes a simple MPPT controller using a FOC technique.
- The measured peak power efficiency was 97.5% and MPPT accuracy was greater than 99%.
- The proposed circuit does not require any external voltages, start-up circuitry, or even DC-DC boosters, which makes it well suited for self-powered miniature-sized sensor node applications.

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