Chip Design Contest

Low-Power Energy Harvesting Power Management Circuit with Thyristor-based Self-Startup, Active Diode, and MPPT for Wearable Electronics

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I. INTRODUCTION

This paper presents an advanced power management system (PMS) designed for low-cost wireless devices, including sensor nodes, IoT devices, and medical implants. The system incorporates a boost DC-DC converter integrated circuit with an off-chip inductor and a maximum power point tracking (MPPT) circuit optimized to extract power from thermoelectric generators (TEGs) with an efficiency of about 93.2%. Additionally, an active diode is used to reduce reverse current and achieve energy conversion efficiency of up to 80.4%. The PMS is implemented using a 0.18 μm CMOS process aimed at reducing power loss and boosting the overall efficiency of energy harvesting systems for low-power applications.

II. DESCRIPTION

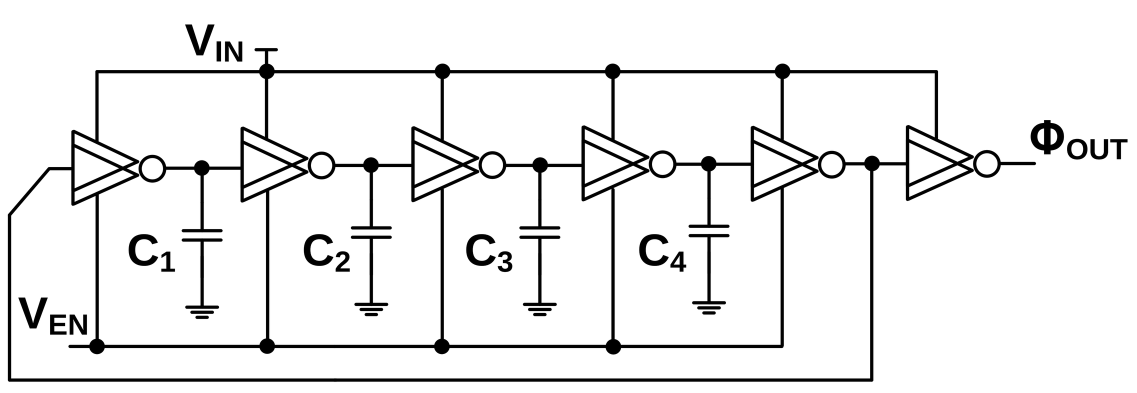

Fig. 1. Block diagram of the conventional CMOS ring oscillator

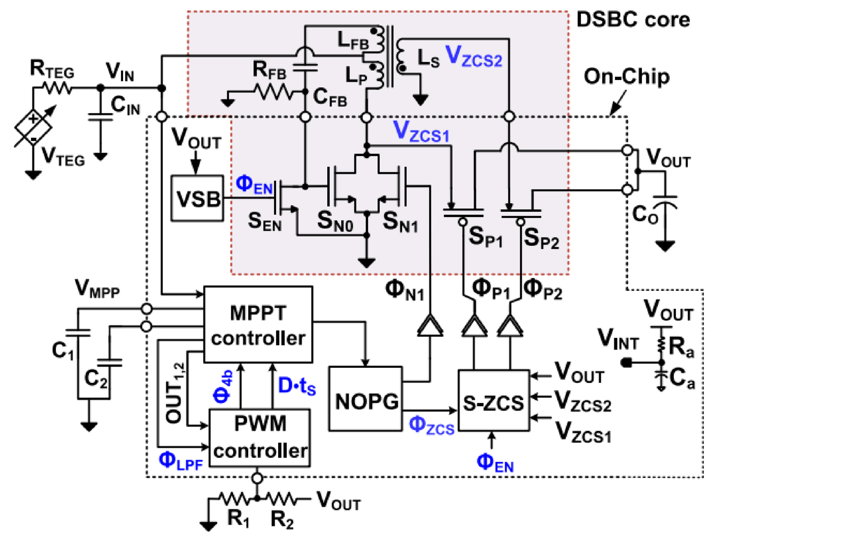

Fig. 2. Block diagram of the dual-stage boost converter with bulky transformer for startup.

Fig. 1 shows the conventional CMOS ring oscillator. The conventional CMOS ring oscillator generates a signal with a high-frequency range. Creating a low-frequency signal in the range of hundreds of Hz with a conventional CMOS ring oscillator requires adding more inverters, which in turn raises the circuit's static power dissipation [1]. Thus, the delay time τ can be calculated as [2]

$$\tau = C\int \frac{dv}{I}$$

where the τ is inversely proportional to the transconductance

$$\tau \propto \frac{1}{g_m}$$

Fig. 2 shows the dual-stage boost converter. The system consists of a dual-stage boosting technique, MPPT, pulse width modulation (PWM), and zero current switching (ZCS). This design does not require any external battery, which simplifies the system. However, to achieve startup from low voltage, the system relies on a bulky transformer, which may increase the overall size and the cost of the system. Also, the transformer can introduce electrical losses and reduce the power conversion efficiency of the system [3].

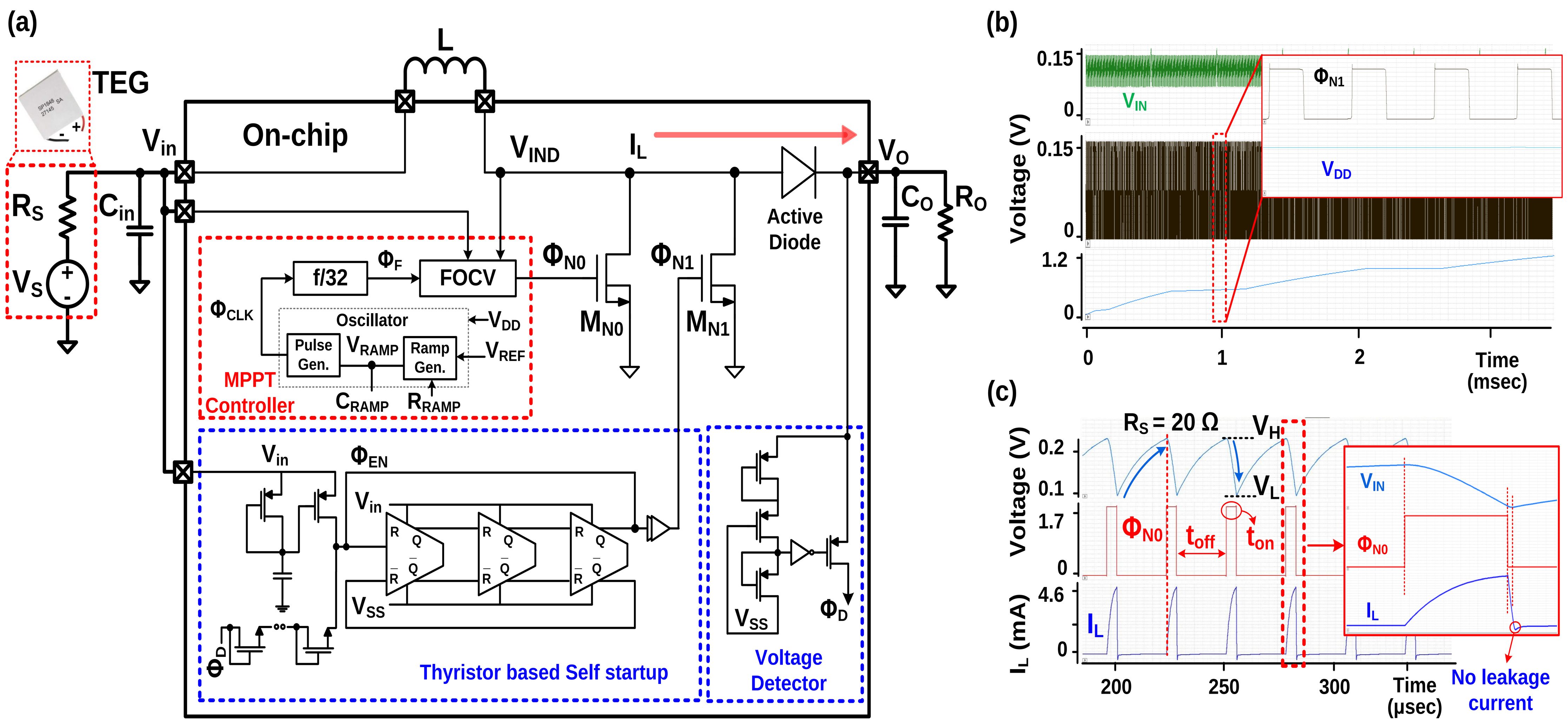

Fig. 3. (a) Block diagram of the proposed system architecture (b) simulated startup, (c) simulated MPPT operations.

Fig. 3(a) shows the proposed system architecture. It mainly consists of a thyristor-based self-startup circuit, MPPT controller, voltage detector, and active diode. In this system, the self-start boost converter architecture is energy-efficient and operates even at a minimum voltage of 150 mV. In order to maximize its power efficiency, this converter uses an external inductor, an active diode to ensure unidirectional current flow while preventing leakage, and an MPPT system using the fractional open circuit voltage (FOCV) approach. Fig. 3(b) shows the waveform of the thyristor-based self-startup. When the V_{DD} voltage reaches 800 mV, the startup operation is turned off, and the normal operation is started. The MPPT enables optimal power extraction from the source, and an active diode is used to prevent the reverse current flow, as shown in Fig. 3(c).

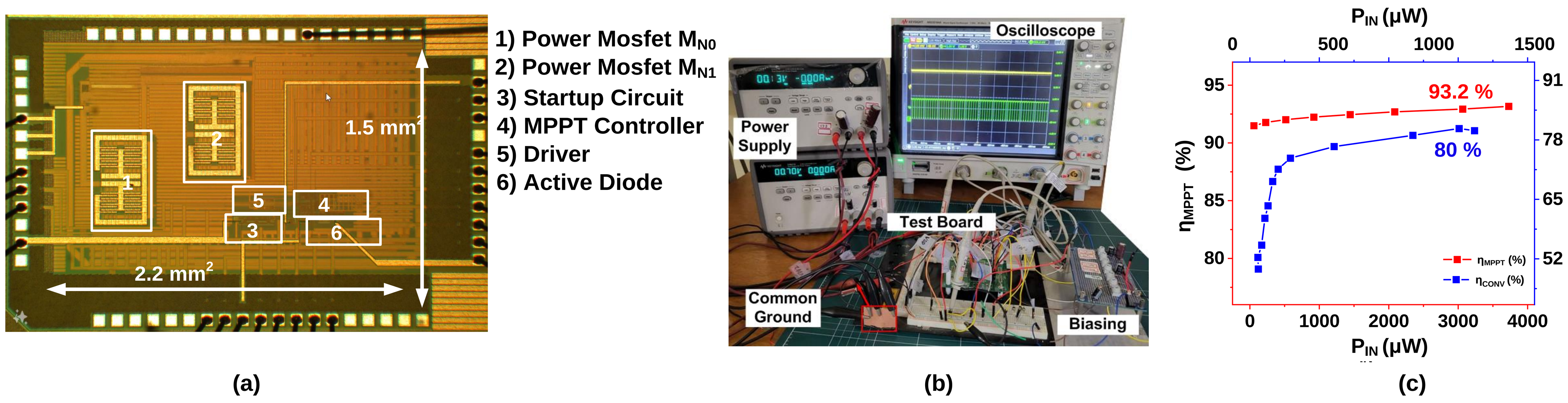

Fig. 4. (a) Die photograph of fabricated IC, (b) measurement setup, and (c) measured efficiencies of the converter.

Fig. 4(a) shows the microphotograph of the fabricated proposed boost converter with a 180-nm CMOS process, and it is mounted on the test board using the chip-on-board technique. Fig. 4(b) shows the measurement setup. Fig. 4(c) shows the tracking efficiency $\eta_{MPPT} = (P_{IN}/P_{Max})$ as a function of P_{IN}. The results show that $\eta_{MPPT} > 93\%$ is achieved in the P_{IN} range from 1 mW to 4 mW, with the peak η_{MPPT} of 93.2% and the conversion efficiency $\eta_{CONV} = (P_{OUT}/P_{IN})$ as a function of P_{IN}. The peak η_{CONV} = 80.4% is achieved for P_{IN} = 1.12 mW.

Conclusion

In this work, we propose a boost converter for the TEG source. The self-startup works at 150mV. MPPT and an active diode is used. The active diode circuit is specifically designed to prevent the flow of reverse current and reduce power loss, leading to improved efficiency in the converter. The ZCS sometimes has early and late switching, which can cause a high voltage drop and negative inductor current. Active diode is better than zero current sensing in terms of reducing negative inductor current.

References

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