A 10mm³ Light-Dose Sensing IoT² System
with 35-to-339nW 10-to-300klx Light-Dose-to-Digital Converter

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Abstract

This paper presents a 10mm³ Internet-of-Tiny-Things (IoT²) system that measures light dose using custom photovoltaic cells and a light-dose-to-digital converter (LDDC). The LDDC nulls diode leakage for temperature stability and creates headroom without power overhead by dual forward-biased photovoltaic cells. It also adaptively updates the current mirror ratio and accumulation weighting factor for a low, near-constant power consumption. The system can operate energy-autonomously at >500lx light level. The LDDC achieves a 3σ inaccuracy of ±3.8% and /g305//g541 of 2.4% across a wide light intensity range from 10lx to 300klx while consuming only 35 – 339nW.

Introduction

Millimeter-scale Internet-of-Tiny-Things (IoT²) systems open new capabilities in a variety of application spaces such as biomedical, security and energy exploration [1]. Cumulative light exposure (light dose) is a compelling parameter for IoT² since it can affect psychological and physical health, growth rates and product quality. The main challenge in developing light-dose sensing IoT² systems is limited available power (<100nA) due to battery size constraint. To continuously record light dose without duty cycling, a low-power light-dose-to-digital converter (LDDC) is critical. Previous light sensors typically consumes >4μW ([2], [3]), which far exceeds the IoT² power budget.

Proposed Circuit

In this paper, we present a 10mm³ light-dose sensing IoT² systems using a new low-power LDDC that consumes only 35 – 85nW at <500lx ambient light condition. With integrated custom photovoltaic (PV) cells, the entire system achieves energy-autonomy at >500lx. The LDDC achieves a 3σ inaccuracy of ±3.8% across 23 chips from -20 – 85°C and /g305//g541 of 2.4% from 3.6 – 4.2V supply.

Measurement Results

The LDDC circuit was fabricated in 180nm CMOS. The two PVs were fabricated in GaAs on a single custom die (Fig. 4). Fig. 5 – 8 show the measurement results of LDDC. The proposed LDDC achieves a 3σ inaccuracy of ±3.8% after individual 2-point & batch calibration across all the available 23 samples and /g305//g541 of 2.4% from 10 – 300klx while consuming only 35 – 339nW. It shows -2.5/1.3% variation across -20 – 85°C and -0.42/0.27% across 3.6 – 4.2V supply.

References

Figure 1. Conventional LDC (top) and the concept of the proposed LDDC (bottom).

Figure 2. Proposed light-to-frequency conversion using dual PV cells.

Figure 3. Proposed frequency-to-digital converter with adaptive operation for current mirror gain and weighting factor.

Figure 4. Die photo.

Figure 5. Measured inaccuracy.

Figure 6. Measured d/μ.

Figure 7. Measured power and frequency.

Figure 8. Measured dependency on temp. (top) and supply voltage (bottom).

Table I. Performance summary and comparison.