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A Fully Integrated Boost Power Supply with On-Chip Photovoltaic Device

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Abstract

In this paper, we propose on-chip power supply system for a micro system. This power supply system operates application circuit, to achieve a stand-alone chip, referred to as a micro system.

This on-chip boost power supply consists of photovoltaic device, ring oscillator and DC-DC boost converter on a same die. The solar cell outputs about 500 mV and several μW under about 7600 lux lighting. The output voltage of the on-chip solar cell is not sufficient to operate general analog circuits which require more than 1 V. Therefore, DC-DC converter and ring oscillator are designed using standard 0.18μm CMOS technology.

As a result of measurement, the boost power supply on a single chip outputs the voltage above 1 V at the solar cell output voltage of 540mV.

1. Introduction

Recently various electronic devices is miniaturized. However, many of these electronic devices typically require external power supply and packaging. We propose a stand-alone micro system which is fully integrated system on a same die including an energy harvester[1][2]. Therefore, external power supply is not required and it can be expected further downsizing.

Proposed boost power supply consists of on-chip solar cell, bootstrap charge pump DC-DC converter and application circuit on a same die. This system designed by standard 0.18 μm CMOS technology. An example of the application circuit is a RF transmitter shown in Fig. 1.

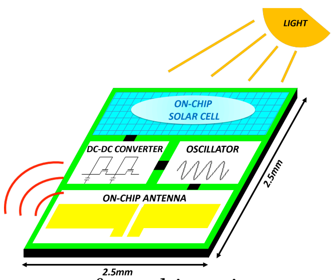

Fig. 1 A concept of on-chip micro system using standard CMOS technology without any packaging.

2. General Instructions

Photovoltaic Device

We designed and measured several types of on-chip photovoltaic devices previously[3]. Among them, we chose n-p- single cell structure that can be extracted the largest power. Figure 2 shows I-V characteristics of the solar cell with about 7600 lux lighting. The solar cell outputs about 500 mV and several μW. However, this structure has two problems. First, p terminal connected to the ground, output from n terminal turns to negative potential. Second, since n-p- solar cell generate a voltage between the substrate and n-well, the solar cell is not able to connect in series. The output voltage of the on-chip solar cell is not sufficient to operate general analog circuits which require more than 1 V. Then, we proposed the way to boost the output of the solar cell by DC-DC boost converter[4].

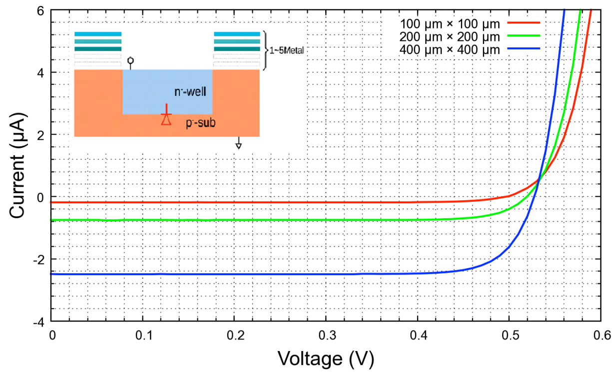

Fig. 2 I-V characteristics of solar cell using 0.18μm CMOS technology under about 7600 lux lighting.

Bootstrap Charge Pump DC-DC Boost Converter

For boosting output voltage of photovoltaic device, we designed 2-stage bootstrap charge pump DC-DC boost converter (BSCP) which is able to operate at low voltage[5]. A proposed circuit of the BSCP is shown in Fig. 3. VDD and Vin are connected to n-well of the solar cell, VSS is connected to the substrate. Therefore, the potential of the substrate is negative, all of the transistors are placed on a deep n-well.

To prevent the backflow, the driver generates a delay to 4 phase clocks (BSCLK, CPCLK). 4 phase clocks are generated by 5-stage ring oscillator (RO) and driver circuits. The RO and the driver are also operated by the same solar cell. The ideal output voltage of the n-stage BSCP is calculated as follows.

$$V_{out} = V_{in} + V_{CLK} \times (n-1) \qquad (1)$$

Results of the BSCP measurement are shown in Fig. 4. The BSCP is supplied clock signals at 25 kHz and 500 mVpp. The outputs of the measurement are approximately 200 mV lower than the simulated results.

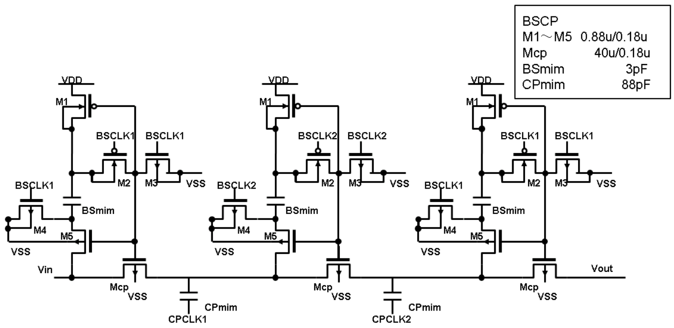

Fig. 3 Schematic of 2-stage bootstrap charge pump DC-DC boost converter (BSCP).

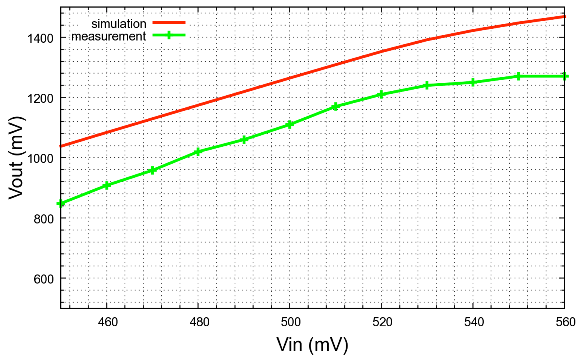

Fig. 4 Vin-Vout characteristics of BSCP (clock Vpp and frequency are 500 mV and 25 kHz, respectively).

Boost Power Supply

Fig. 5 shows a block diagram and a micrograph of a fully integrated power supply. The solar cell is the size of 400 μm × 400 μm (600 μm × 600 μm with guard ring). The boost power supply circuits (BSCP, RO and driver) occupy approximately 500 μm × 1300 μm. Frequency of the RO is 10 kHz, 100 kHz and 520 kHz at 400 mV, 500 mV and 600 mV, respectively. Measurement results of the boost power supply are shown in Fig. 6. When the output voltage of the CMOS solar cell (Vsc) exceeds 540 mV, the output of on-chip boost power supply (Vout) exceeds 1V.

3. Conclusions

We designed a fully integrated power supply system using 0.18 μm CMOS technology. This system is composed of photovoltaic device, 5-stage ring oscillator, buffer and 2-stage bootstrap charge pump DC-DC converter on a same die. The solar cell of 400 μm × 400 μm outputs about 500 mV and several μW. Then output of the solar cell is boosted to 1 V by DC-DC boost converter. As the results, the output voltage of the on-chip boost power supply is achieved more than 1 V.

Acknowledgements

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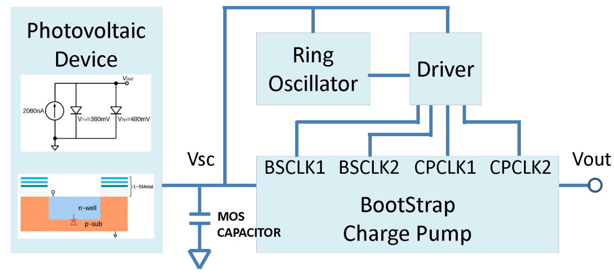
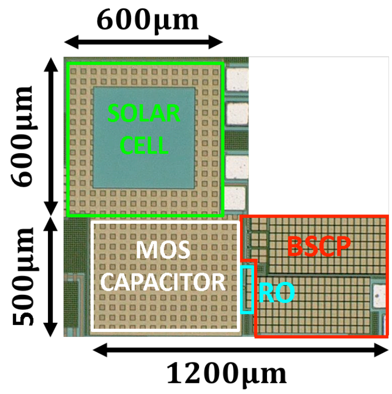


(a)



(b)

Fig. 5 (a) Block diagram and (b) micrograph of boost power supply for micro system.

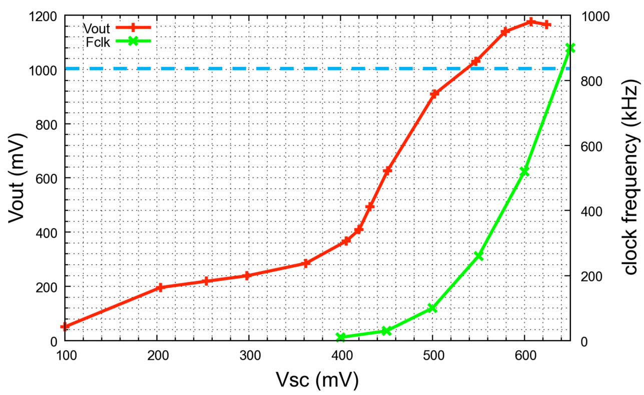


Fig. 6 Vout (output voltage of a fully integrated power supply) and Fclk (clock frequency) under the condition Vsc (on-chip solar cell voltage) with changing intensity of light.

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