

**A 0.21-V Minimum Input, 73.6% Maximum Efficiency,
Fully Integrated 3-Terminal Voltage Converter
with MPPT for Low-Voltage Energy Harvesters**

**Toshihiro Ozaki, Tetsuya Hirose,
Takahiro Nagai, Keishi Tsubaki,
Nobutaka Kuroki and Masahiro Numa**

KOBE UNIVERSITY, JAPAN

Background



□ Large scale sensor networks

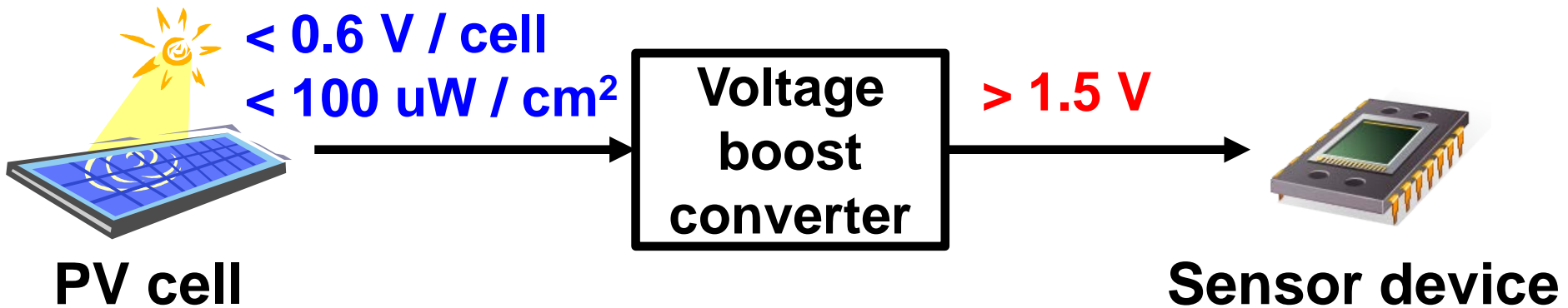
Demand for **battery-less sensors**

□ Light energy harvesting

– Photovoltaic (PV) cell

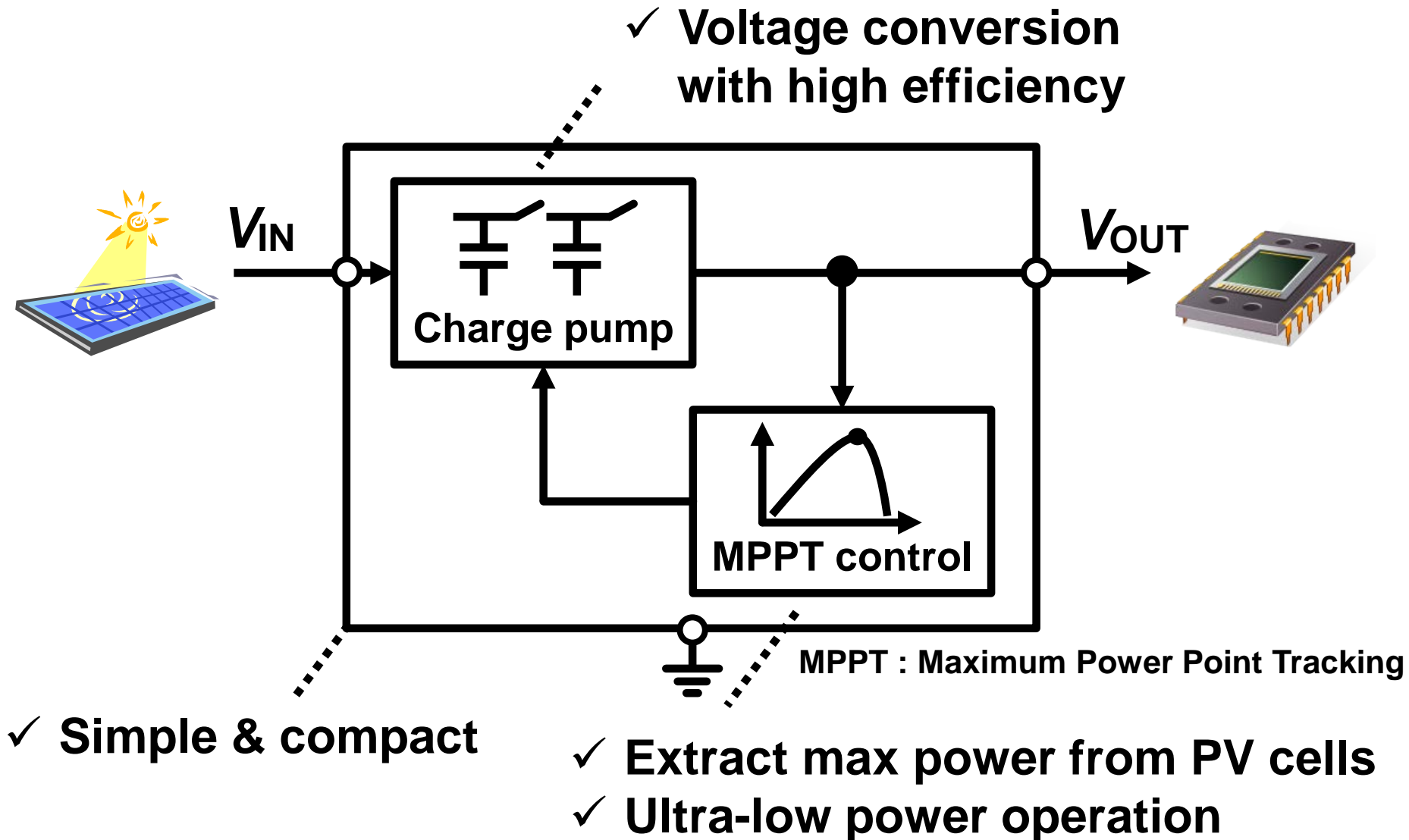
Advantages: compact & low cost

Challenges: low voltage & power

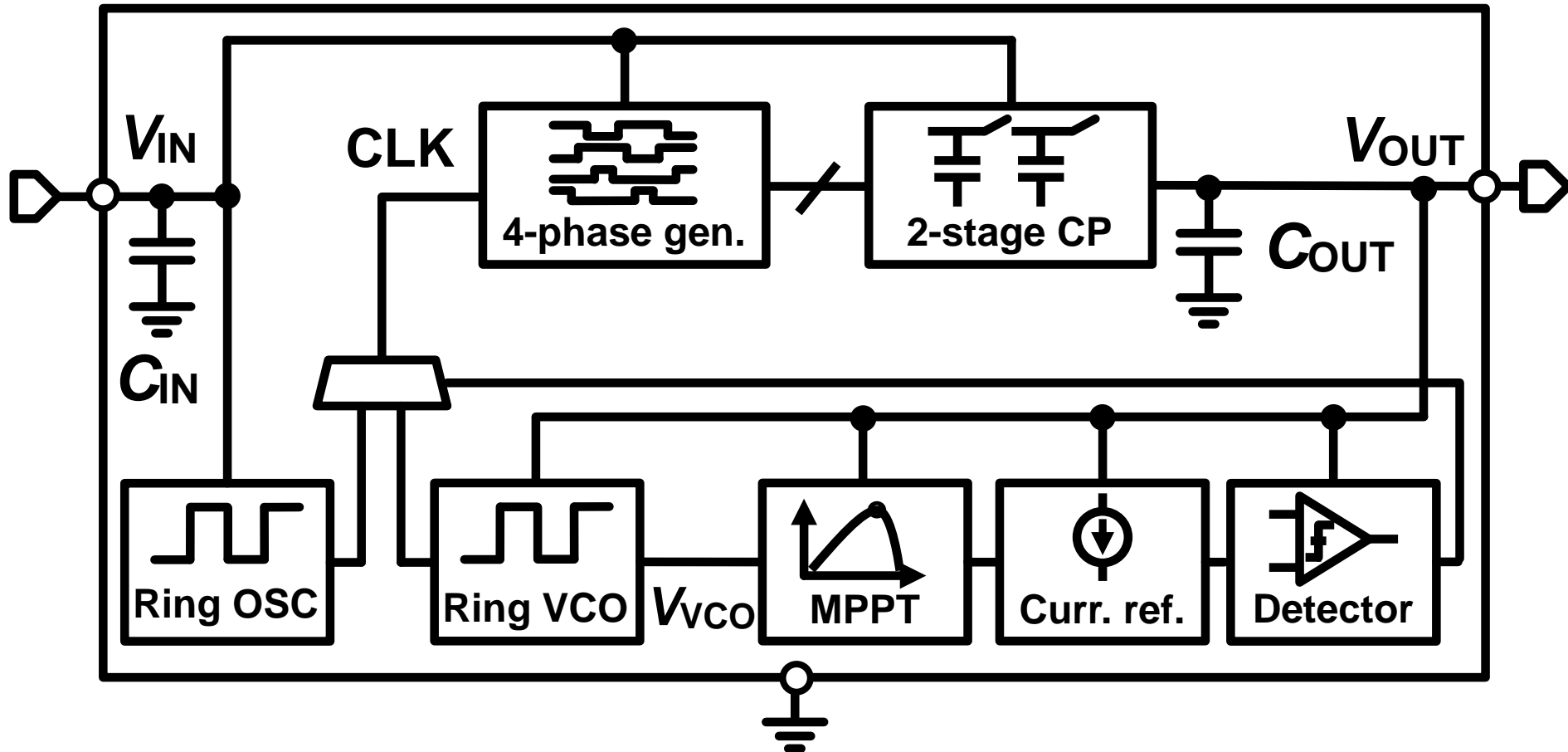


A highly efficient voltage converter is required

Voltage Boost Converter



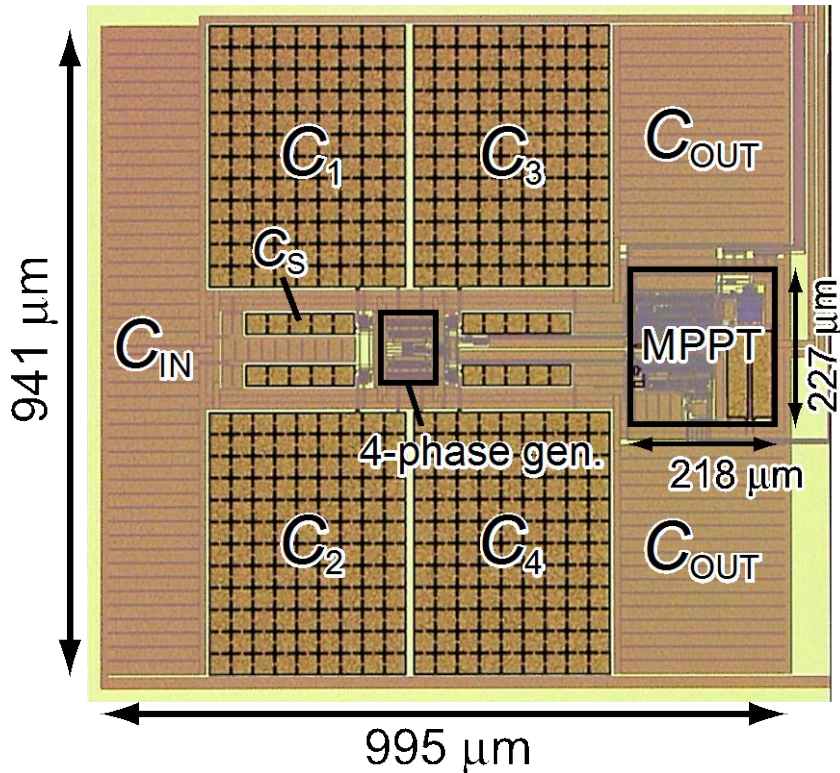
Proposed Architecture



- ✓ Charge pump with MOSFET drivers
- ✓ Nano-watt power MPPT control circuit
- ✓ Fully on-chip with 3 terminals

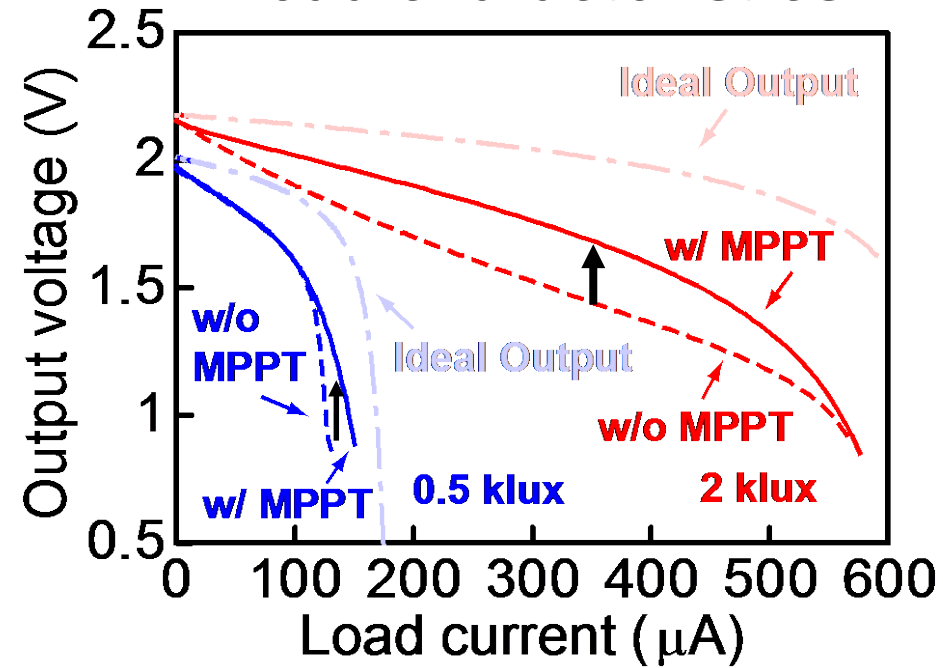
Chip Micrograph & Results

0.18- μm CMOS



Area: 0.94 mm²

Load characteristics



*PV cell was used

Output characteristics
were improved
with MPPT control

Comparison

| AMP | This work | [1] | [2] | [3] |
|-------------------------------------|---------------------------------|------------------------|--------------------------------|---------------------------------|
| Technology | 0.18- μm | 0.35- μm | 0.35- μm | 0.13- μm |
| Area (mm^2) | 0.94 | 59 | 2.28 | 0.066 |
| V_{IN} (V) | 0.21 – 0.65 | > 0.6 | 1 – 2.7 | > 0.15 V |
| V_{OUT} (V) | 0.6 – 1.8 | 0 – 3.3 | 2 (regulated) | 0.62 @ $V_{\text{IN}}=0.18$ |
| Throughput | 0 – 1 mW | 0.01– 1 mW | 0– 80 μW | N/A |
| Efficiency (%) | 73.6 @ 348 μW | 70 | 86 @ 35 μW | 72.5 @ 20.3 μW |
| Power density | 370 $\mu\text{W} / \text{mm}^2$ | N/A | 15 $\mu\text{W} / \text{mm}^2$ | 308 $\mu\text{W} / \text{mm}^2$ |
| MPPT | V_{OUT} Sens. | I_{OUT} Sens. | V_{OUT} Sens. | No |
| P_{MPPT} (μW) | 0.25 – 0.74 | 2.4 – 3.5 | 0.45 – 0.85 | N/A |
| Accuracy | 95.7 – 99.8% | N/A | N/A | N/A |
| Off-chip cap. | No | N/A | N/A | 10 nF |

Low-voltage input and highly efficient operation
with **no off-chip capacitors**

[1] I. Doms et al., *ISSCC 2009*, pp. 300-301.

[2] J. Kim et al., *IEEE Trans. Circuits Syst.*, pp. 802-806, 2011.

[3] J. Kim et al., *ISSCC 2014*, pp. 394-396.