An Inductor-less MPPT Design for Light Energy Harvesting Systems

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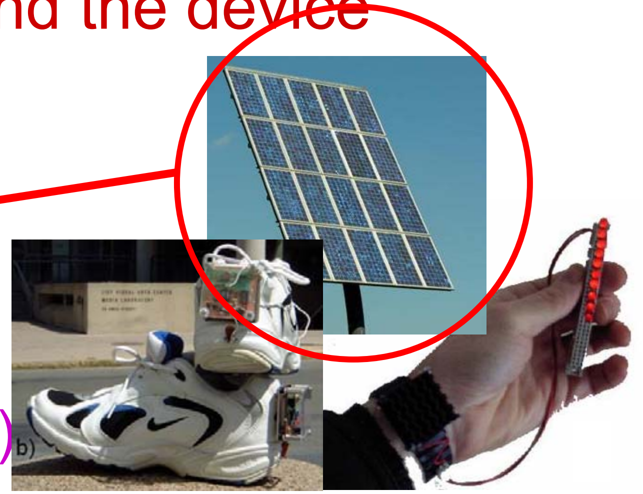
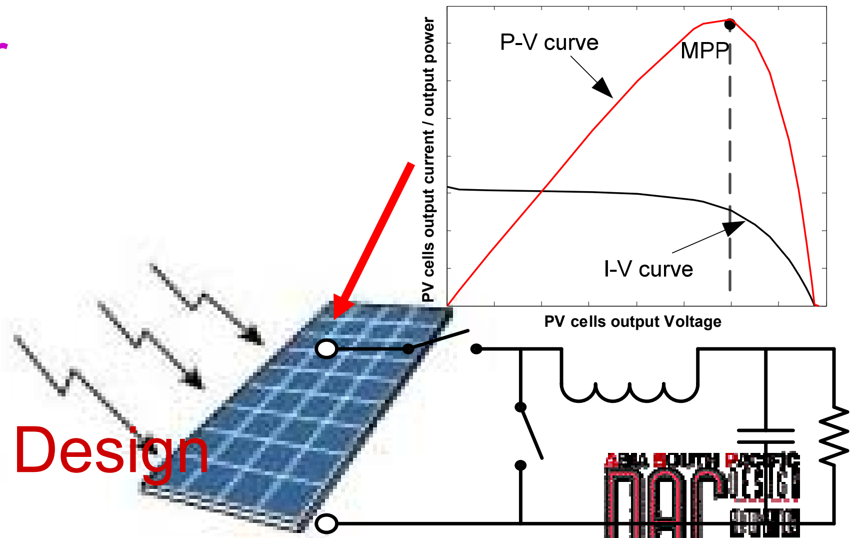
Introduction

- Energy harvesting techniques – to extend the device lifetime for micro-system designs

  Solar energy: The most popular because of its ubiquitous spreading, high power density, etc.



- Previous works of solar systems
  - ► Maximum Power Point Tracking (MPPT)
    - > Extract maximum power from solar cell
  - ► MPPT using DC-DC converter
    - > Inductors are costly
  - ► Strong sunlight assumption
    - > Low light condition
      - » Voltage step up needed
- Our work: Inductor-less MPPT Design



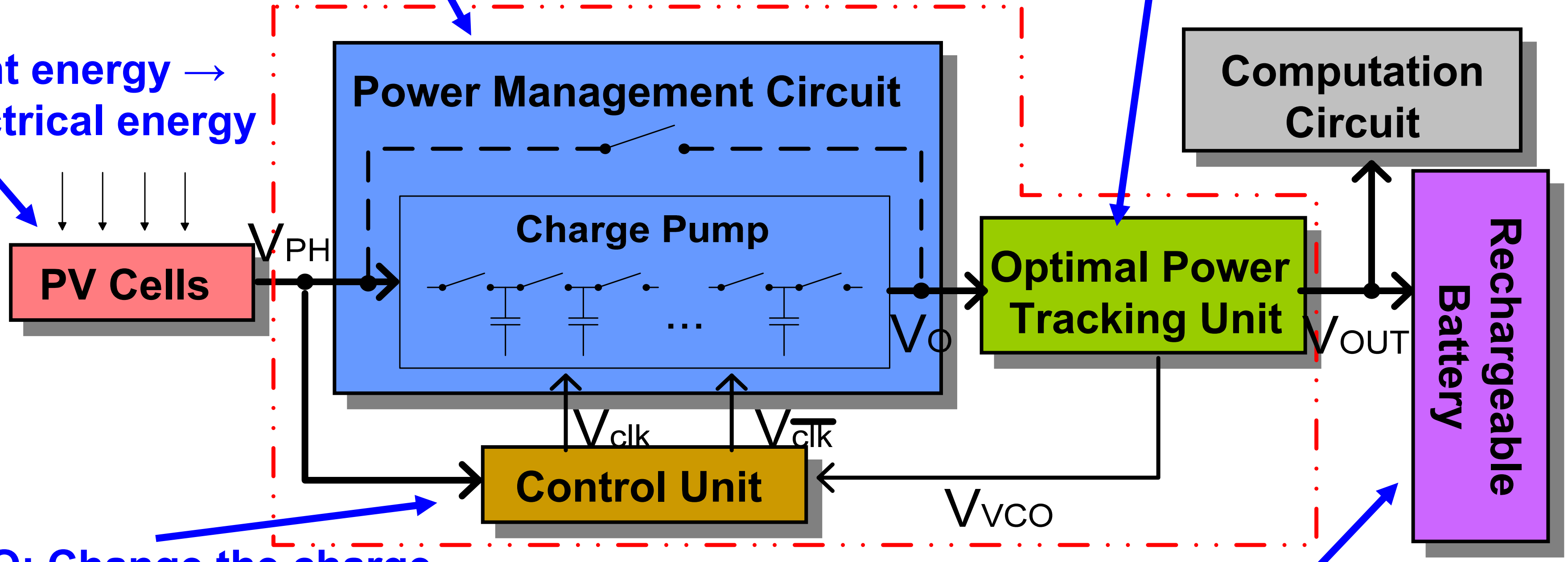
System Description

Under low light condition:
Charge pump steps up the voltage
(Inductors avoided)

Track the maximum output power point:

1. **Monitor the power from the charge pump**
2. **Adjust V_{VCO} to maximize the output power based on generic hill climbing algorithm**

Light energy → Electrical energy



VCO: Change the charge pump switching frequency based on the V_{VCO} value

1. **Energy buffer for system continuous operation**
2. **Voltage clamper to fix system output voltage**

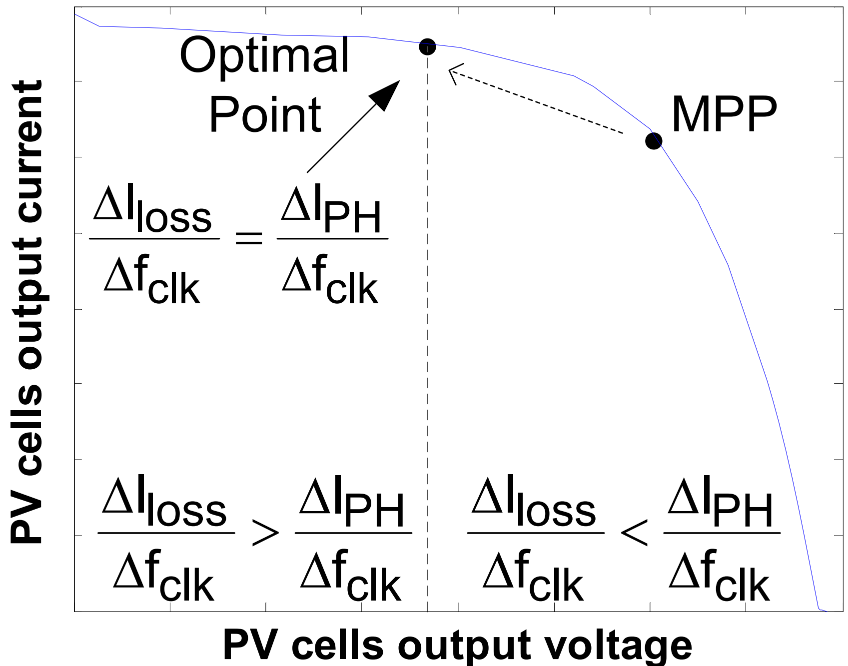
Maximizing system output power = Maximizing system output current

System Operating Behavior

- System output current is determined by I_{PH} and I_{loss}

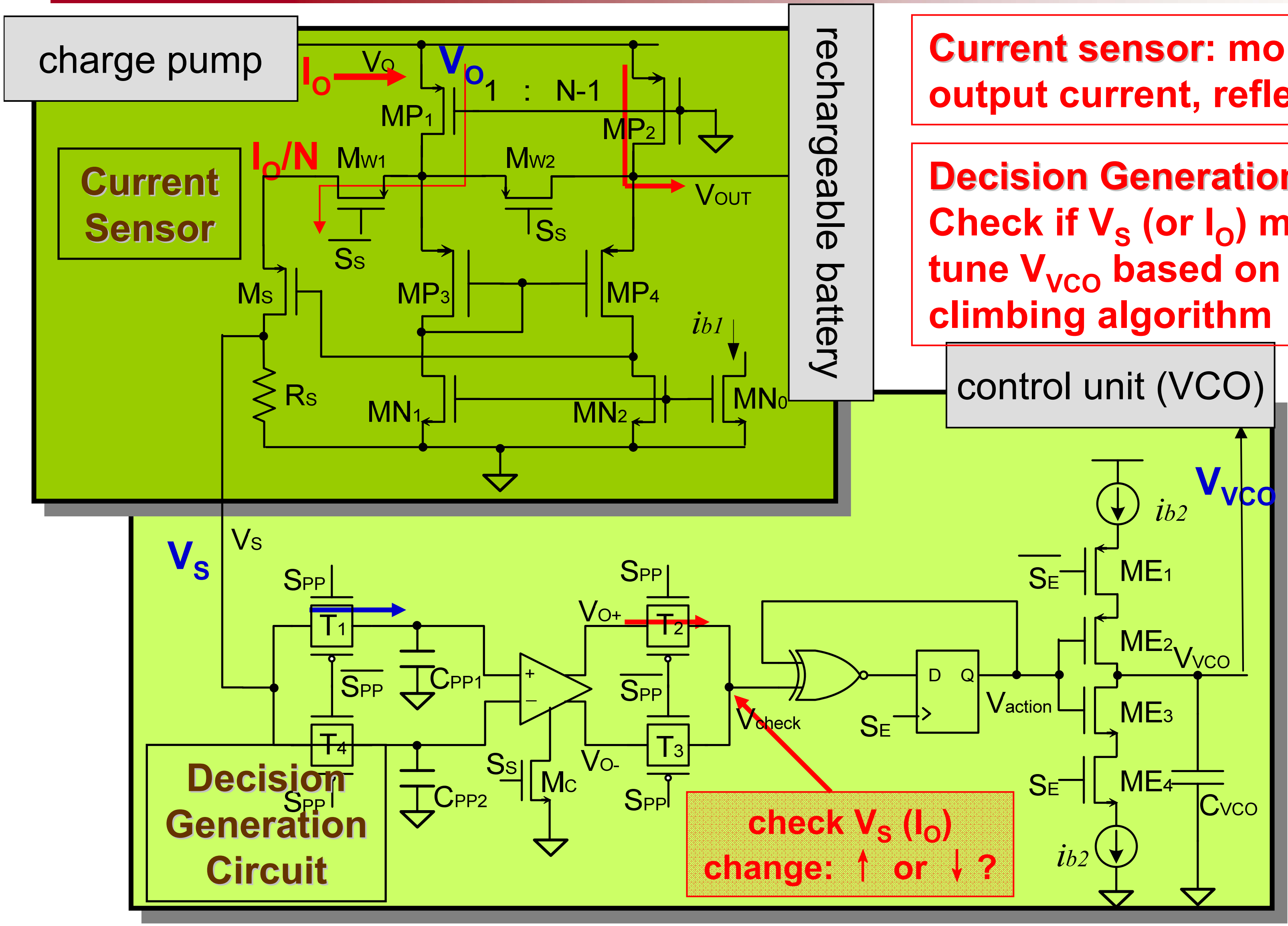
$$I_{CP,O} = \frac{1}{N+1}\{(1-\frac{C_E}{\alpha})[\underbrace{I_{PH}(V_{PH})}_{I_{PH}} - I_{amp}] - \underbrace{(\sigma + \frac{C_E\beta}{\alpha})f_{clk}}_{I_{loss}}\}$$

- System MPP is usually different from PV cells' MPP
  - $f_{clk}=0$
    - $I_{PH}=0$, $I_{loss}=0$
      - **$I_{CP,O}=0$**
  - $f_{clk}\uparrow$
    - $(I_{PH}\uparrow) > (I_{loss}\uparrow)$
      - **$I_{CP,O}\uparrow\uparrow$**
  - $f_{clk}\uparrow$
    - $(I_{PH}\uparrow) < (I_{loss}\uparrow)$
      - **$I_{CP,O}\downarrow\downarrow$**



- System MPP can be tracked by implementing hill climbing algorithm with tuning f_{clk}

System Maximum Output Power Control



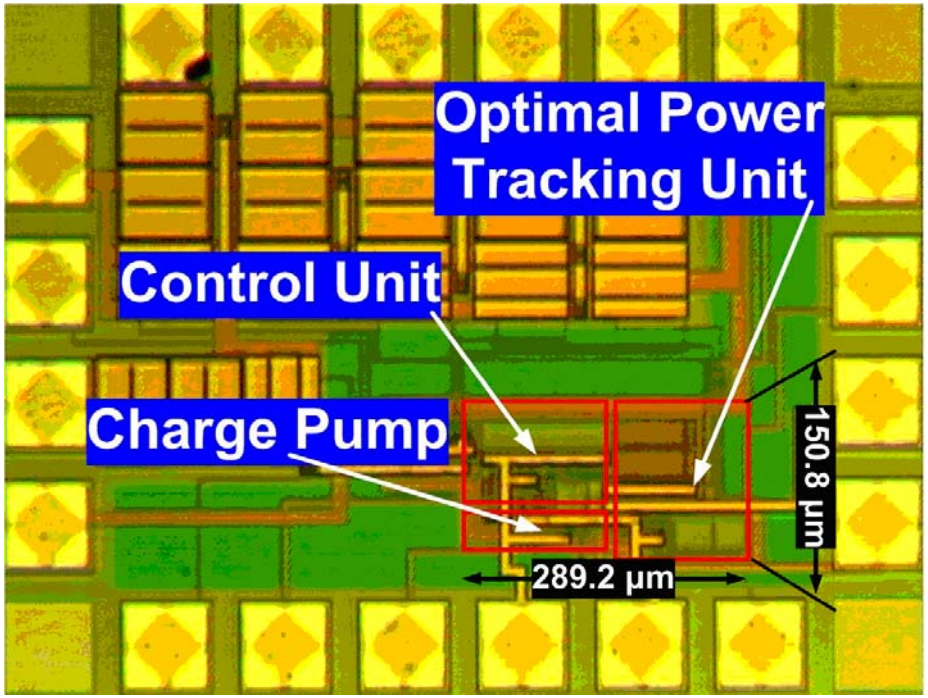
Current sensor: monitor system output current, reflect it by V_S

Decision Generation Circuit: Check if V_S (or I_O) maximum and tune V_{VCO} based on generic hill climbing algorithm

Low power techniques are implemented to reduce the circuit power overhead

Experimental Results

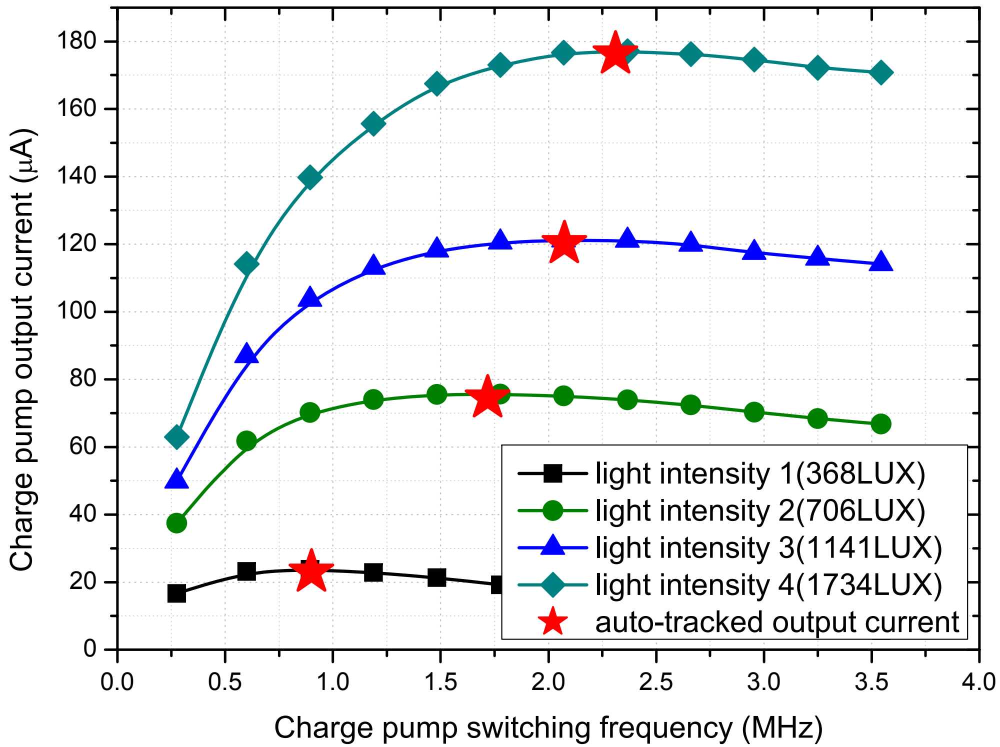
- Test chip was fabricated in AMS 0.35μm process
  - Source: 2 mono-crystalline solar cells (area: 6cm x 6cm)
  - Charge pump: 1-stage voltage doubler
  - Load: a 125mAh Li-ion rechargeable battery



Die micro-photograph of the proposed system

Measurement Results

- Operation of the optimal power tracking unit (OPTU)
  - ► Disable OPTU: Tune f_{clk} to check the system ideal MPP
  - ► Enable OPTU: Auto-track the system MPP well



System output current vs. charge pump switching frequency

Experimental Results

Comparison of system output power & power efficiency at the system ideal MPP and when applying MPP tracking control scheme

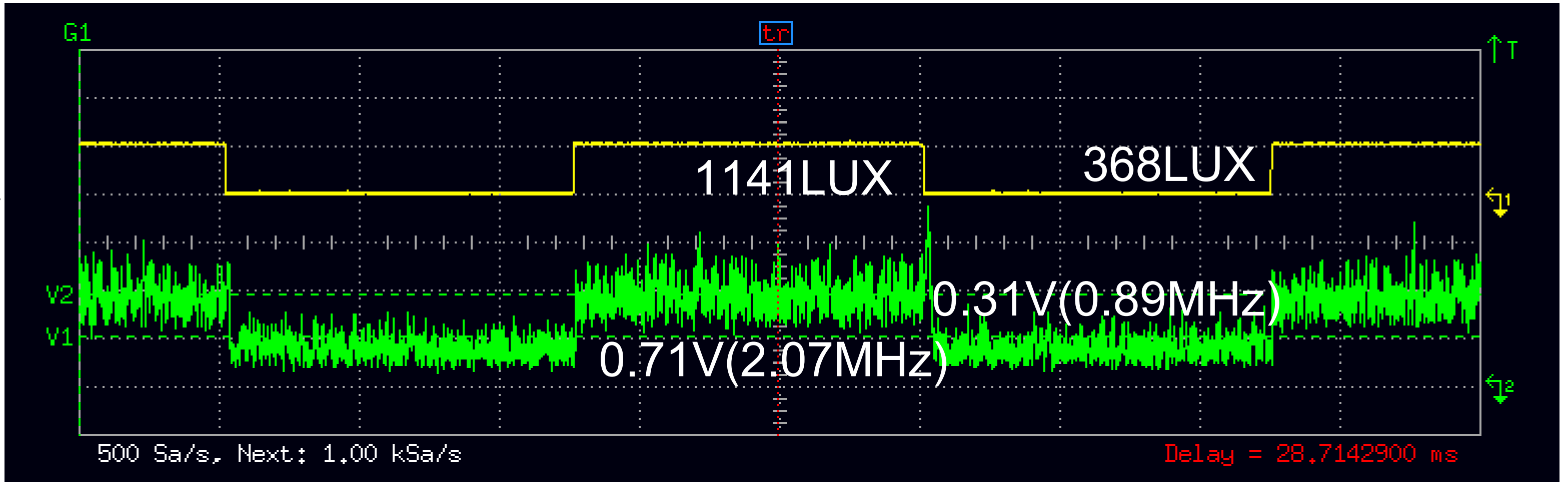
light intensity	system ideal maximum P_{OUT} / η	system P_{OUT} / η with MPPT
368 LUX	106.63 μW / 53.65 %	100.72 μW / 50.65 %
706 LUX	332.99 μW / 64.60 %	327.49 μW / 63.24 %
1141 LUX	533.02 μW / 67.22 %	528.76 μW / 67.08 %
1734 LUX	779.24 μW / 66.95 %	775.50 μW / 66.82 %

Measurement Results

- Under same light intensity
  - ► V_{VCO} oscillates around the system MPP
- When light intensity changes
  - ► V_{VCO} tracks the light change and goes to the new MPP

light intensity

V_{VCO}



System MPP tracking when light intensity changes