Power and Energy Management in the context of the SiNAPS Project

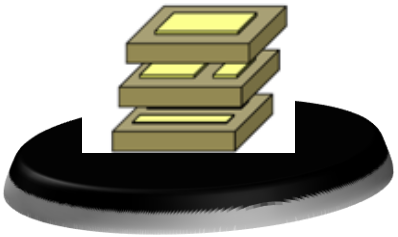
Maher Kayal
Electronics Laboratories

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Outline

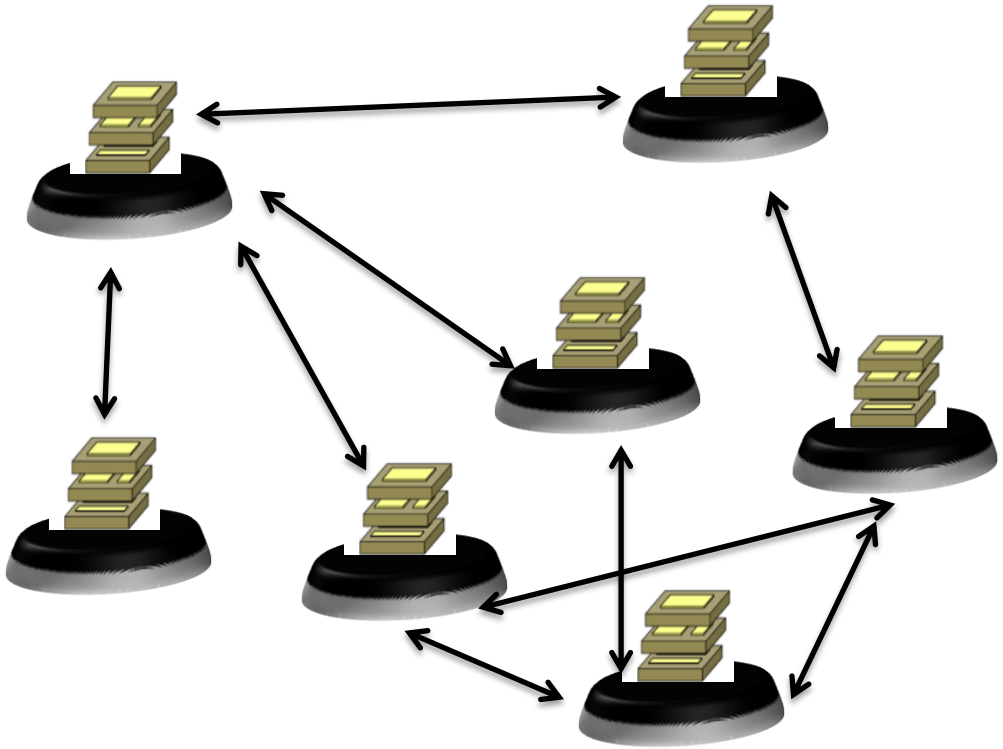
- **Introduction:**
  - SiNAPS Motes: Target Application
  - Sinaps Power Budget, *pushing the limit*
- **System-Level Overview:**
  - Basic Concept, Charging Process
- **System-Level Design:**
  - Challenges Overview: Energy Storage, Battery Charging
- **Sinaps Power Management Circuit:**
  - Energy Management & Storage
  - Battery Management
- **Conclusion & Follow Up**

SiNAPS Motes: Target Application



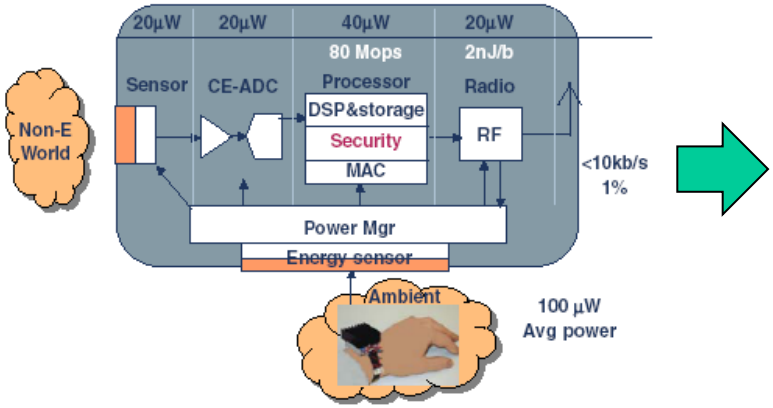
SiNAPS Mote Electronics:

- **Power Management,**
- **Sensor Readout,**
- **Data Transmission**



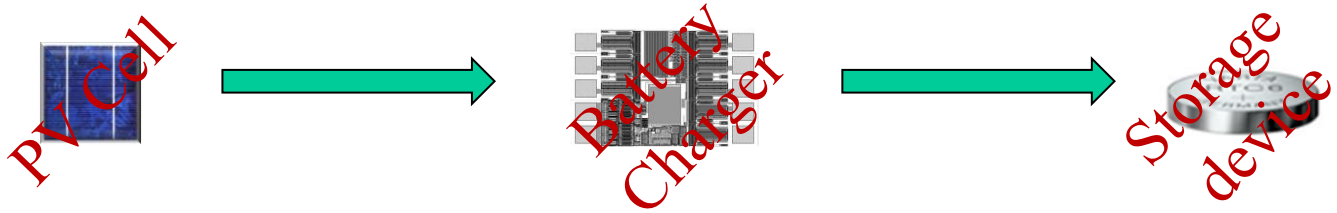
SiNAPS Network

Sinaps Power Budget, *pushing the limit*



K. Baert *et al*, Microelectronics Journal 37, 1563 (2006)

- ***New Energy Management Paradigm:***
  - Reconfiguring system according to harvested energy
  - Targeting highest overall efficiency
- ***Extremely low power block:***
  - Sensor Interface: Sensor, CE-ADC
  - Power & energy Manager

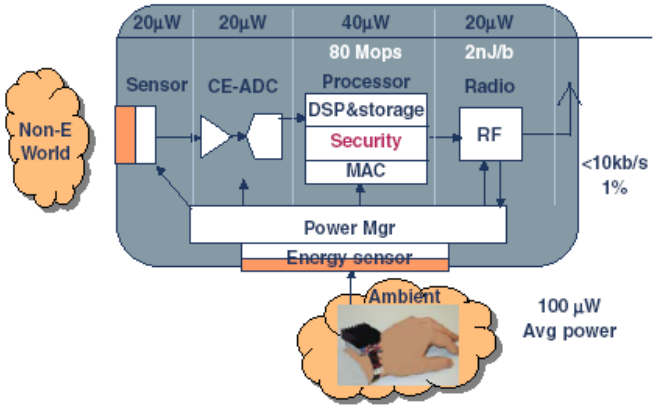


Demanded Specs:
- High efficiency → Small Area
- Appropriate Voltage Level

Design Considerations:
- Intermittent Harvested Energy
- Extremely low power
- High Efficiency & Small Area

Why Needed?
- Intermittent Harvested Energy
- Peak Power during RF TX/RX
- Stable voltage for Electronics

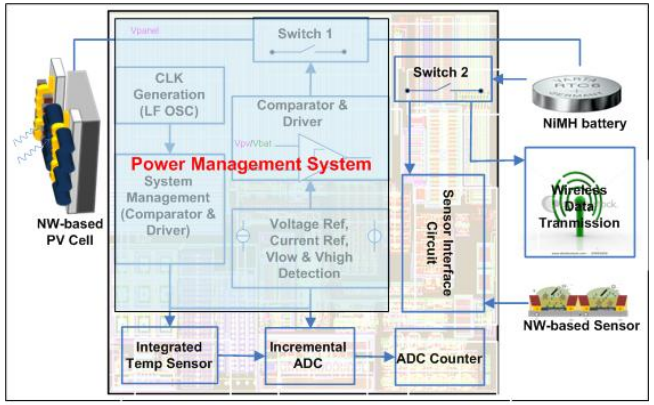
Sinaps,
New Energy Management Paradigm



K. Baert *et al*, Microelectronics Journal 37, 1563 (2006)

Traditional Approach:

- **Assigned Power Budget:**
  - Average power of energy harvester
- **Optimization Goal:**
  - Meeting target Design Specifications with minimum power
- **Power Consumption:**
  - Usually not reconfigurable

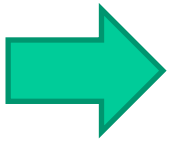


Reconfigurable Approach:

- **Optimization Goal:**
  - Reconfigurable specifications and power consumption according to available energy

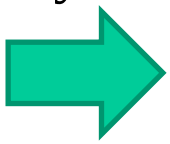
System-Level Design: Challenges Overview

- **Energy Storage Specifications:**
  - Miniaturized Size
  - Nominal Voltage Level
  - High Discharge Current
  - Energy Capacity
  - Internal Resistance
  - Life Cycle



- ❑ Supercapacitors?
- ❑ Miniaturized Li-ION Batteries?
- ❑ Thin Film Li-ION Batteries?
- ✓ **Miniaturized NiMH Batteries?**

- **Power Management System:**
  - Optimizing the overall efficiency
  - Targeting area requirements



- ❑ Switched Capacitor DC-DC Converter?
- ❑ Inductor-based DC-DC Converter?
- ✓ **Direct Charging?**

System-Level Design: Energy Storage Option

Energy Storage Option	Advantages	Disadvantages
Miniaturized Supercaps	▪ High Output Power ▪ Very High Life Cycle	▪ Very Low Energy Capacity ▪ Fast Voltage Drop ▪ Very High Leakage ▪ Limited Output Power
Thin Film Li/ION Batteries	▪ Low leakage Current ▪ High Cycle Life	▪ Big Area ▪ Very Low Output Power ▪ Low Capacity ▪ High Nominal Voltage
Miniaturized Ni-MH Batteries	▪ Very High Output Power ▪ High Capacity ▪ Low Nominal Voltage	▪ Higher leakage Current ▪ Lower Life Cycle

System-Level Design: Miniaturized Batteries

Battery/ Specification	Varta (MH 13654)	Seiko (MS412FE)	Seiko (TS518FE)
Technology	**NiMH**	Manganese Silicon Lithium	Titanium Silicon Lithium
Nominal Voltage	**1.2V**	3V	1.5V
Size	**D: 6.8mm H: 2.15mm** ☹	D: 4.8 mm H: 1.2 mm	D: 5.8 mm H: 1.9 mm
Capacity	**6.2mAh (@1.2mA, down to 1V)** ☺	1mAh (down to 2.0V)	1.5mAh (down to 1.0v)
Internal Res (DC)	**9Ω** ☺	100Ω	120Ω
Discharge Current	**18mA** ☺	0.1mA	0.15mA
Cycle Life	**1000**	1000	1000

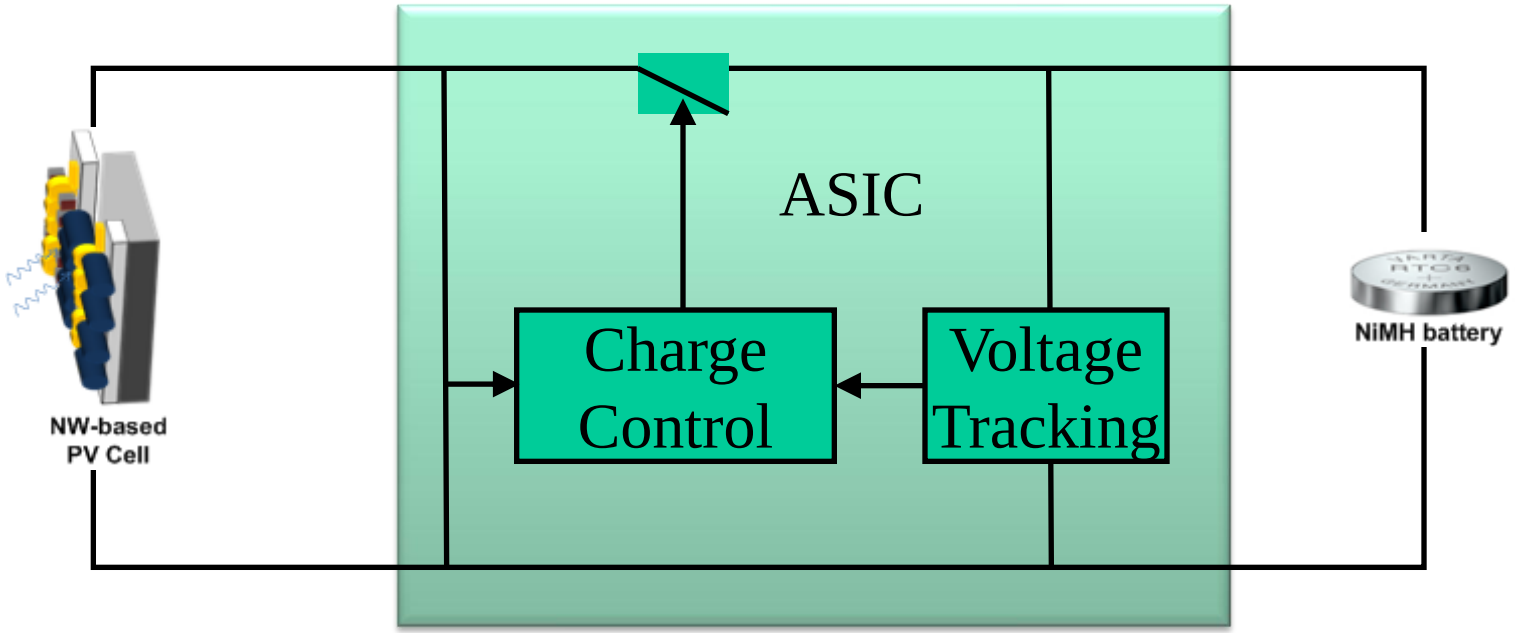
System-Level Design: Battery Charging Solution

Solution	Advantages	Disadvantages
Inductor-based DC-DC Converter	▪ High Potential Efficiency ▪ Voltage Up/Down Implementation ▪MPPT[1] Implementation (Potential High Accuracy)	▪ Big Area (Inductor → Normally External) ▪High Power Consumption of PMC[2]
Switched Capacitor DC-DC Converter	▪ Voltage Up/Down Implementation ▪ MPPT Implementation (Stepwise)	▪ Low Efficiency ▪ Big Area (Using Big Capacitors) ▪ High Power Consumption of PMC
Direct Charging	▪ Potential High Efficiency ▪ Small Area ▪ Low Power Consumption of PMC	▪ Only Voltage Down Implementations ▪ No MPPT Implementation

1. MPPT: Max Power Point Tracking

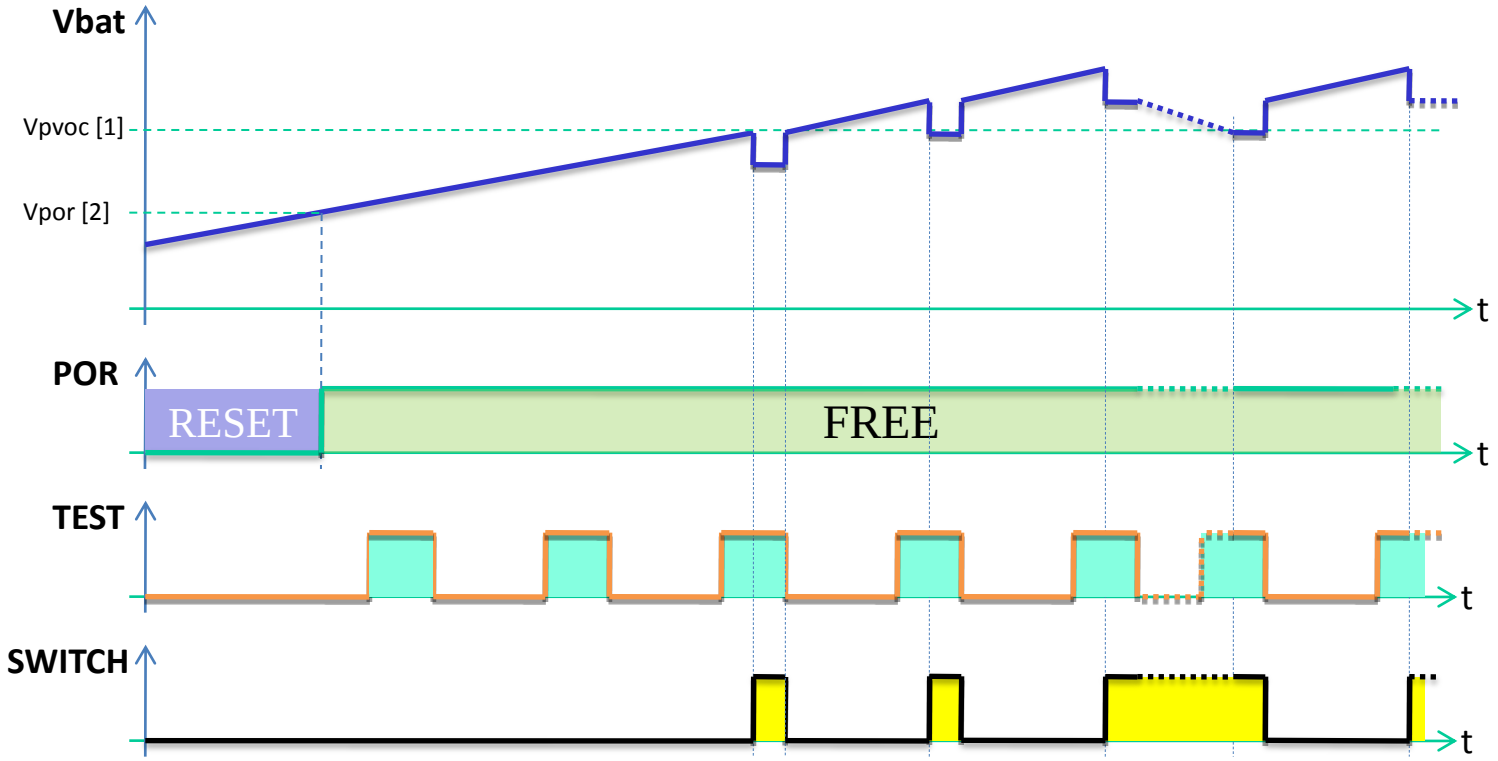
2. PMC: Power Management Circuit

System-Level Overview: Basic Concept



- High efficiency
- Low-power analog implementation
- Small silicon area ASIC

System-Level Overview : Charging Process

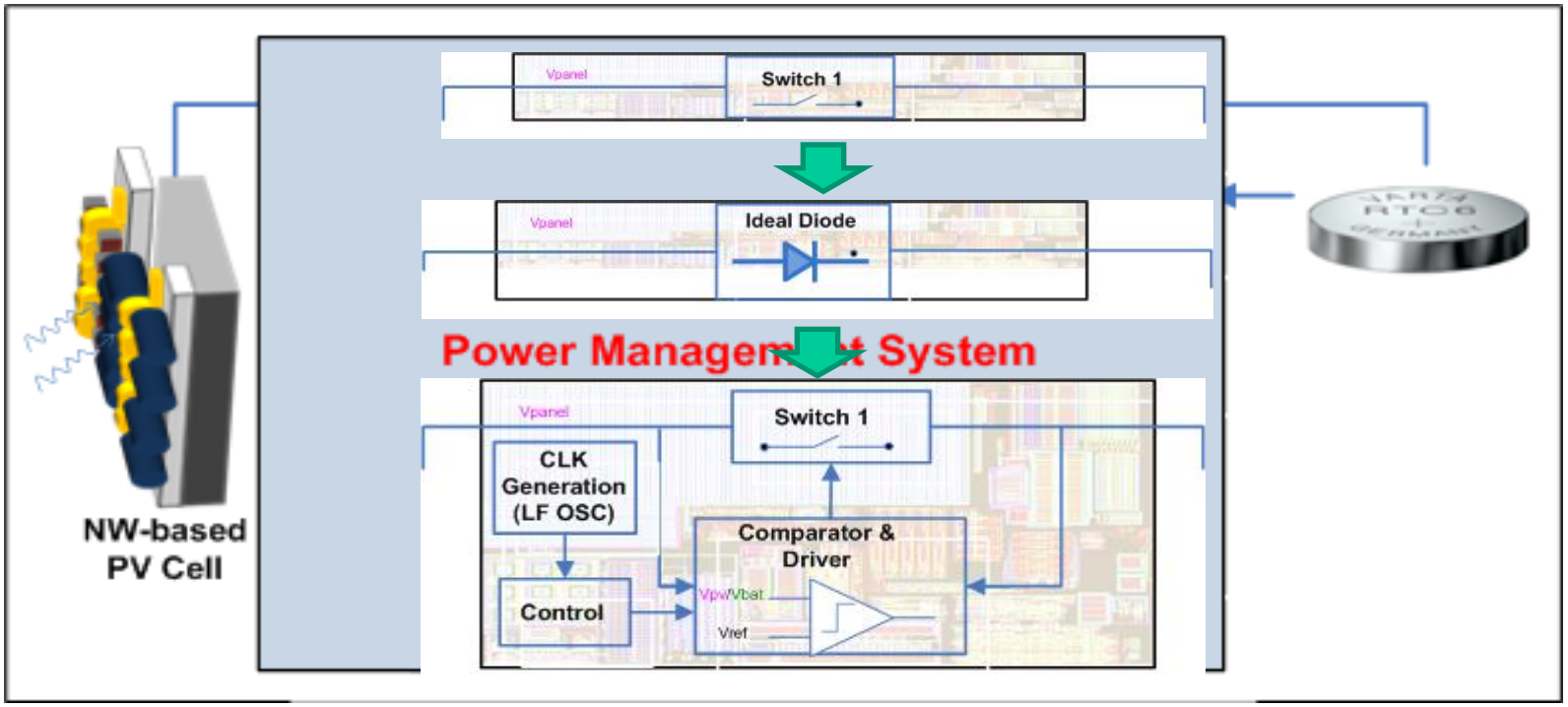


1. Vpvoc= Open Circuit Voltage of PV Cell

2. Vpor= Power-On-Reset Voltage

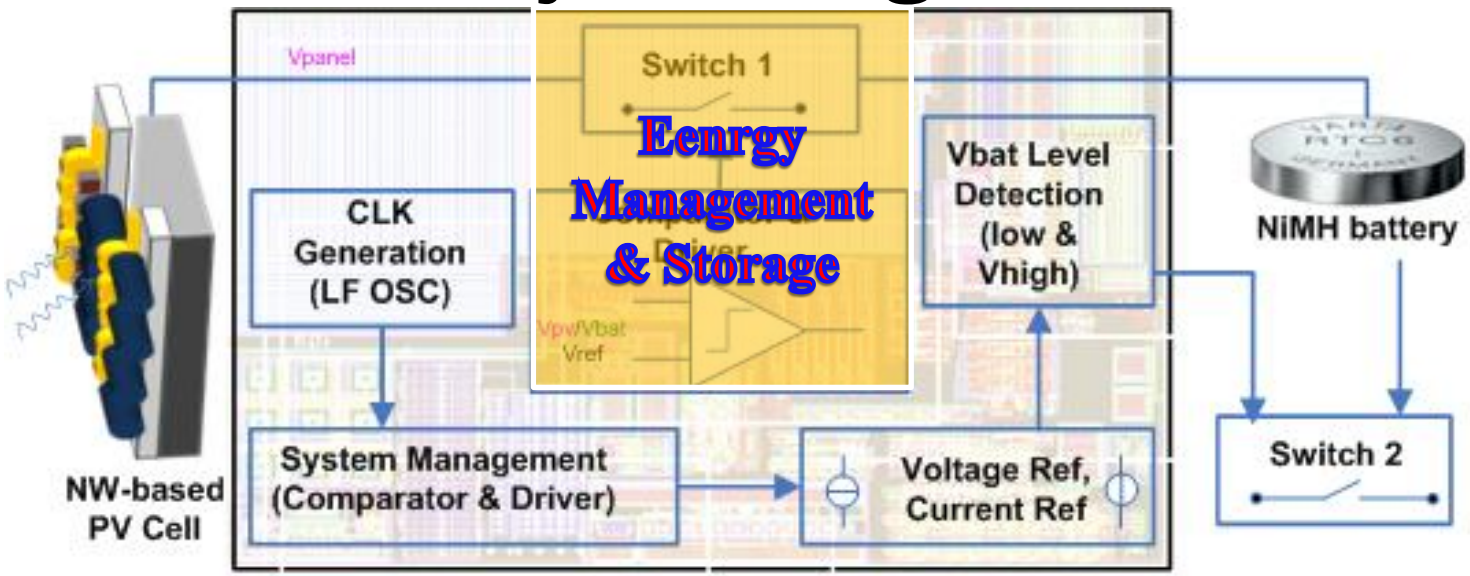
- The battery voltage is periodically compared to V_{pvoc}
- The switch is opened to compare Vbat and Vpv

Sinaps Power Management Circuit: Energy Management & Storage



- **Methodology:** Direct Charging from PV cell to NiMH Battery
- **Advantage:** High Efficiency, Simplicity, Low Power Consumption, No External Component

Sinaps Power Management Circuit: Battery Management

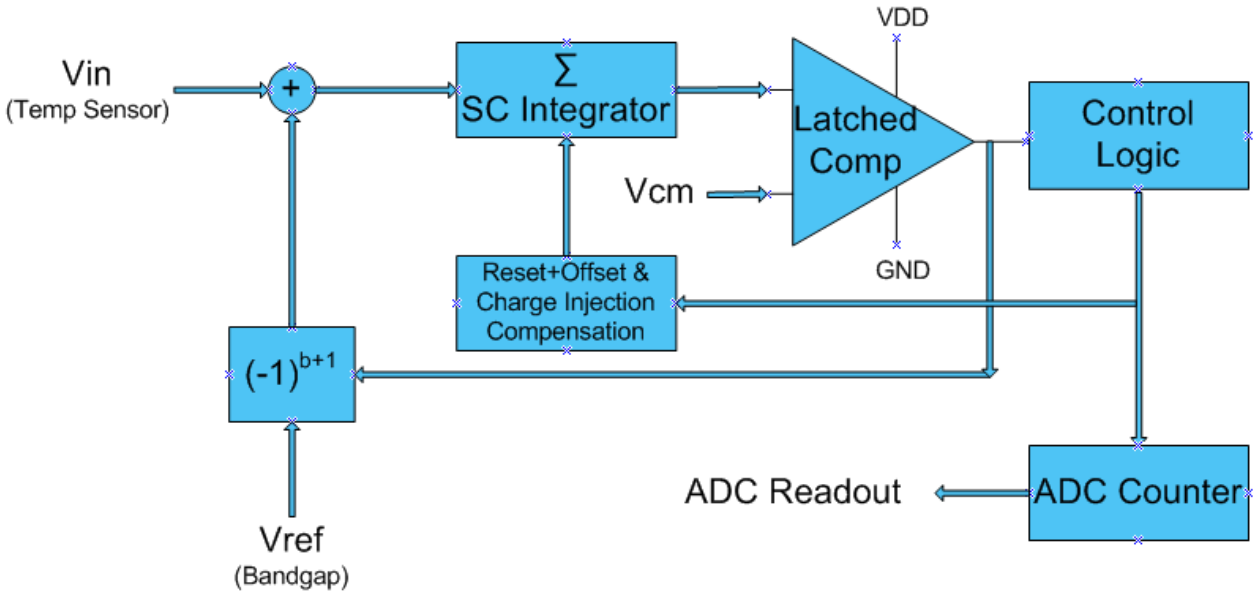


- **Battery Voltage Level Detection:**
  - **Vthlow:** POR (Power On Reset), **Vthhigh:** Enabling data transmission
- **Design Parameters:** Battery Specification, Temperature

Battery	Volt.	Capacity/ Size	I_{out}	R_{out}	Main Disadvantages
Varta V6HR (MH13654)	1.2V	6.2mAh/ D: 6.8mm, H: 2.15mm	18 mA	9Ω	Loosing 20% in 1 month → 1.72 µA

Sinaps Power Budget: Sample Reconfigurable Approach

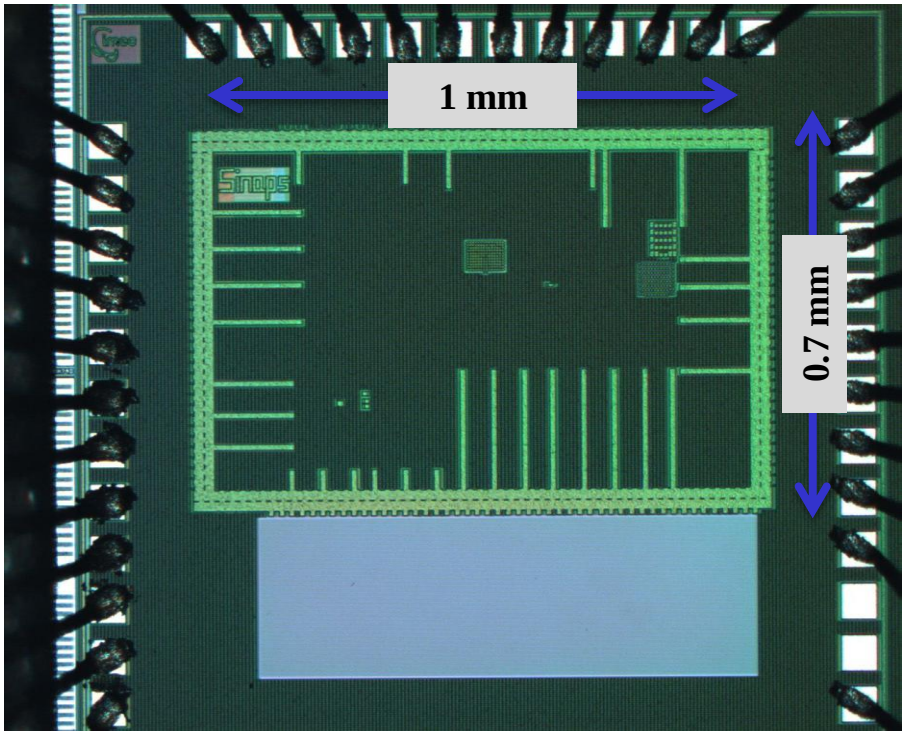
Integrated Temperature Sensor with 12bits ADC



- **Methodology:** Reconfigurable resolution & conversion rate according to available energy
- **Design Approach:** Low Power, Small Area, Low Frequency, Switched-Capacitor based Circuits

Conclusion & Follow Up

- **Fully Integrated Power Management System**
  - ✓ No External Component
- **Technology:** UMC 0.18
- **Power Consumption** ≈ 300nW
- **Area (Power Management)** ≈ 0.5 *0.5 mm^2



- Implementation Details →

  "**Sinaps: Electronics Implementation of Power and Energy Management Scheme"** by Naser Khosro Pour @ 11:40