A 330nA Charger and Battery Management IC for Solar and Thermoelectric Energy Harvesting

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Texas Instruments
Self-Powered Applications

- Solar Keyboard
- Electronic Shelf Labels
- Occupancy Sensor
- Environmental Awareness
- Hard to Reach
- Smoke Detector
- Pipelines
- Oil Rig

Convenience
Energy Harvesting System

Solar

Energy Harvester

Thermo electric

MPPT

Battery Management

Power good indicator

Interface

Charger

Regulator

Cold Start

Radio Micro Proc.

Charger, Regulator and Battery Management
Outline

- Design Goals
- Chip Architecture and Circuit Details
- Experimental Results
- Summary
Design Goals

Energy Input 80mV to 3V
330mV cold start
300mW max power
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Open circuit voltage based maximum power point tracking
0% to 100%
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Under voltage and Over voltage
2.2V to 5.25V
+/- 3% Accuracy
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330mV cold start
300mW max power

Open circuit voltage based maximum power point tracking
0% to 100%

Under voltage and Over voltage
2.2V to 5.25V
+/- 3% Accuracy

Battery OK
2.3V to 5.25V
Design Goals

Battery / Super cap
2.2V to 5.25V

Energy Input 80mV to 3V
330mV cold start
300mW max power

Open circuit voltage based maximum power point tracking
0% to 100%

Under voltage and Over voltage
2.2V to 5.25V
+/- 3% Accuracy
Overall Chip Architecture

- Charger and MPPT
- Cold Start
- Battery management
- Battery isolation switch
- House keeping
  - Reset
  - Oscillator
  - Bias
Charger Architecture

- Synchronous boost converter with **input regulation**
- **Hysteretic controller** with 55nA quiescent current
- **Fractional open circuit voltage** based MPPT
- Zero power from battery for MPPT
Controller Architecture

- Main comparator detects if VIN_DC > VREF to enable charger
- COMP2 detects OV condition to turn off charger
- Safety timers to detect saturation
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Charger Operation

When VIN_DC > VREF, OV = lo, CHG_EN = hi
- LS_ON = hi and LS_ON remains high till I_L hits I_SET.

Once CS1 goes high (i.e. I_L=I_SET),
- LS_ON =lo and HS_ON = hi

HS_ON remains high till I_L = 0 (CS2 detects this)
Current Sensor

- Feedback controlled current sensor
- Sensed current is 4000 (=N) times smaller than inductor current
Controller Architecture

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- COMP2 detects OV condition to turn off charger
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Output voltage determined by OV setpoint
Maximum Power Point Tracking

- Open circuit voltage based MPPT
- Charger periodically turned off using EN signal
- IC samples and holds fraction of OCV on external capacitor
- Charger regulates input to value held on capacitor

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<thead>
<tr>
<th></th>
<th>Solar</th>
<th>TEG</th>
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<tr>
<td>MPPT fraction</td>
<td>~80%</td>
<td>50%</td>
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• Independent, resistor programmable UV, OK, OV
• State machine with low power 2kHz oscillator
• Duty cycled and sampled reference
Batt. Management Architecture

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Battery Isolation

• VSTOR node connected to battery only after UV
• Prevents battery damage
Main Oscillator

Regulator

- Relaxation oscillator frequency ~ 2kHz
- Sub-regulation reduces quiescent current
- $I_q \, 50\text{nA} \, @ \, 27^\circ\text{C}$ and 100nA across temperature
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Cold Start

- Function: Start system with depleted battery
- Architecture: \textbf{Input} powered boost converter
- Startup voltage / power = 330mV / 5uW
Cold Start Circuit

- Low $V_t$ low side switch
- Body diode of main charger high side switch
Cold Start Circuit

Power on reset
330mV threshold

- Body diode of main charger high side switch
- Low $V_t$ low side switch
Cold Start Circuit

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Cold Start Circuit

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Normal System Startup

- VBAT_OK
- VSTOR
- VBAT

Switch between VSTOR and VBAT closes at UV

Open circuit voltage sampling for MPPT

Cold Start

Charger On

OV

Battery at OV = 3.3V

Battery OK goes high

VIN = 330mV
Maximum Power Point Tracking

- Input Open Circuit Voltage (OCV): 2V
- Charger regulates VIN to 80% of OCV
- Periodic sampling of OCV

Input Voltage (VIN):
- 1V
- 1.6V
- 0.8V

Sampling intervals:
- 16s
- 16s
Charger Efficiency

- **Single** cell solar operation in indoor light (200 lux)
- Harvesting from thermo electric generators

### Eff Vs lin

![Graph showing efficiency vs input current](image)

- 35% efficiency with 10uA input at 0.5V
- >80% above 100uA.

### Eff Vs Vin

![Graph showing efficiency vs input voltage](image)

- 38% efficiency with 100mV input at 10mA
- >80% above 0.5V
Battery Management

- Quiescent current: **180 nA**
- Trip point accuracy < +/-2% (untrimmed)

30 devices measured at -40, 27 and 85°C
Mean: 1.24V
Sigma: 4.3mV

- OV and UV range: **2V to 5.5V**
Summary

- Technology: 0.35um
- Iq = 330nA
- Charger
  - > 80% eff @ 0.5V
  - Zero power MPPT
  - Harvest from 80mV and 5uW of power
- Cold Start
  - 330mV and 5uW of power
- Battery Management
  - Independently programmable UV, OK, OV, OT
  - Li-ion, NiMH, Supercaps

Complete battery and power management solution for energy harvesting
Acknowledgements

• Colleagues at TI
  – Karthik Kadirvel
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