BEXUS23 OSCAR: Solar cell I-V monitoring system for space environments

Steven Nagels

23d ESA Symposium on European Rocket and Balloon Programmes and Related Research
Who are we?

Who is OSCAR?
Our mission

Optical Sensors based on CARbon materials

Thin film solar cells
Diamond magnetometer

Adapted from: Kaltenbrunner et al., Nat. Mater. 1032-1039(2015)
Our samples

<table>
<thead>
<tr>
<th>#</th>
<th>Cell Type</th>
<th>V range</th>
<th>I range</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>IPV</td>
<td>0.00 --- 7.00V</td>
<td>-119 --- 411mA</td>
</tr>
<tr>
<td>B</td>
<td>MAPI</td>
<td>0.00 ---- 1.00V</td>
<td>-6.75 --- 3.50mA</td>
</tr>
<tr>
<td>C</td>
<td>PBDTTDP PCBM</td>
<td>0.00 --- 1.00V</td>
<td>-3.00 --- 14.0mA</td>
</tr>
<tr>
<td>D</td>
<td>CPDTQx PCBM</td>
<td>0.00 --- 0.85V</td>
<td>-3.00 --- 3.50mA</td>
</tr>
<tr>
<td>E</td>
<td>IAPP F4 SnPc</td>
<td>0.00 --- 0.85V</td>
<td>-1.07 --- 2.80mA</td>
</tr>
<tr>
<td>F</td>
<td>IAPP DCV5T ZnPc</td>
<td>0.00 --- 1.00V</td>
<td>-1.05 --- 2.10mA</td>
</tr>
</tbody>
</table>

Measure 20 I-V point couples per sweep

Observe cell performance by monitoring fill factor from I-V curve
Basic system

OPAMP based conversion circuits

\[ V_O = \left( \frac{R_2}{R_1} \right) \times (V_2 - V_1) \]

Differential amplifier

Transimpedance amplifier

\[ V_O = -R \times I_{in} \]

12 bit DAC

12 bit ADC

12 bit ADC

12 bit ADC

Solar cell

Trans-impedance conversion

Diff amp rescale & offset

Diff amp rescale & offset

Diff amp rescale & offset

Apply voltage

Measure voltage

Measure current

Current

Voltage

Voltage

Voltage

Voltage
Expanded system

12 bit DAC

1:16 Signal MUX

1:16 GND MUX

Solar cells + Reference resistor

Trans-impedance conversion

Diff amp rescale & offset

voltage

measure voltage

Diff amp rescale & offset

12 bit ADC

12 bit ADC

6 x

12 bit ADC

current

measure current

Solar cells + Reference resistor

Diff amp rescale & offset

1:16 GND MUX

1:16 Signal MUX

voltage

measure voltage

Diff amp rescale & offset

12 bit ADC

12 bit DAC

apply voltage

Type | V range | I range
--- | --- | ---
1x IPVSTRETCH | 0 --- 7.00V | -200 --- 500mA
2x BCF | 0 ---- 1.00V | -6.0 ---- 14mA
3x DEdiode | 0 --- 0.85V | -5.0 ---- 5.0mA

Measuring ranges of each subcircuit

Type | V LSB | I LSB
--- | --- | ---
IPVSTRETCH | 1.709 mV | 170.9 uA
BCF | 0.244 mV | 4.883 uA
DEdiode | 0.208 mV | 2.441 uA

Theoretical resolution of each subcircuit
Software flow

1. **Init**
2. **Read commands from Ethernet**
3. **Perform 96 I-V sweeps**
4. **Report back through Ethernet**
5. **Log data to SD**
6. **Log sysTime to SD**

Flow of operations: Start with the initiative, then read commands from Ethernet, follow with performing 96 I-V sweeps, report back through Ethernet, log data to SD, and log sysTime to SD. The process can be repeated by returning to the read commands from Ethernet step, indicated by the feedback loop.
Electromechanical codesign

- Brackets + spring loaded contacts
- Edge connectors
- RF shielding
Testing

Series resistance influence

Influence of series resistance on IPV

Influence of series resistance on MAPbI

Opamp ringing

BCF1 IMEAS diff amp stage 2
Flight

7th of October 2016
07:07:26 UTC

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Max</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Float time</td>
<td>1.88</td>
<td>4.61</td>
<td>h</td>
</tr>
<tr>
<td>Air pressure</td>
<td>6</td>
<td>997</td>
<td>hPa</td>
</tr>
<tr>
<td>Altitude</td>
<td>333</td>
<td>32290</td>
<td>m</td>
</tr>
<tr>
<td>Temperature</td>
<td>-56.8</td>
<td>22.9</td>
<td>°C</td>
</tr>
<tr>
<td>Vert. speed</td>
<td>-44.4</td>
<td>5.9</td>
<td>m/s</td>
</tr>
</tbody>
</table>

Nominal operation until battery drainage
Results

I-V sweeps from reference resistors

Sweeps at different moments in time

Slope = indication of R = measurement system performance indication
Results

Reference resistance measurements throughout flight
Results

Each of the 5 channels on one graph

Regression coefficients

Sweep No

0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8

System
Results

Relative change of regression coefficients

Plotted for relative change, gain error identified
Gain error corrected
Results

Gain error ~ temperature effect (different TC)
Results

Spin-coated polymer:fullerene PV

Performance remains stable throughout the flight

Cardinaletti et al., manuscript in preparation
Results

Spin-coated polymer: fullerene PV

Performance remains stable throughout the flight

Cardinaletti et al., manuscript in preparation
Results

Spin-coated polymer:fullerene PV

Performance remains stable throughout the flight

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Results

Spin-coated polymer:fullerene PV

Performance remains stable throughout the flight

Cardinaletti et al., manuscript in preparation
Conclusions

• Successful flight

• Many stray variables afterwards

• Organic solar cells did not degrade drastically during flight

• Better in-flight calibration of measuring system was needed
Future work

• Study degradation over longer periods of time (SPB?)

• Study degradation at higher altitudes/more space-like conditions
Advice

- Measure and log your sample’s direct environment
- Put measuring unit in thermally controlled housing
- Use separate test equipment and calibrate your complete system
- Keep a uniform timebase between all your subsystems
- When filtering, log some unfiltered data to monitor filter performance
- Perform offset compensation on opamps
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