SMOS Payload Performance

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**SM-OS** Project

European Space Agency

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EADS-CASA Espacio

and contributions from:

UPC and DEIMOS SMOS project teams
Contents:

- Basic Equations
- Payload Performance Tests
- Performance over Temperature
- Image Validation
- Error Budget
- Future Work
**Basic Equations**

**Corbella Equation**

\[
V_{ij}^{pq} (u, v) = 2k_B \sqrt{B_i B_j} \alpha_i \alpha_j \frac{1}{\sqrt{\Omega_i^p \Omega_j^q}} \times \\
\iint_{\xi^2 + \eta^2 \leq 1} F_{n,i}^{\alpha,p} (\xi, \eta) F_{n,j}^{\beta,q*} (\xi, \eta) \frac{T_B^{\alpha\beta}(\xi, \eta) - \delta_{\alpha\beta} T_r}{\sqrt{1 - \xi^2 - \eta^2}} \\
\sim r_{ij} \left( - \frac{u \xi + v \eta}{f_o} \right) e^{-j 2\pi (u \xi + v \eta)} \ d\xi \ d\eta
\]
Basic Equations

Visibility Key Elements

\[ V_{kj} = \frac{\sqrt{T_{sys,k} T_{sys,j}}}{G_{kj}} M_{kj} \]

NIR

Correlations

PMS
**Basic Equations**

**Imaging (Level-1 Processor)**

1. same antenna patterns
2. no fringe-washing

\[
T = \text{IHFT}\{V\}
\]

\[
T \equiv \frac{T_B - T_r}{\Omega \sqrt{1 - \xi^2 - \eta^2}} |F_n|^2
\]

\[
V_{kj}
\]

**G-Matrix**

\[
T_B
\]
The performance test plan of the SMOS payload included:

- Tests over temperature in the Large Space Simulator (LSS)

- Image validation in the Maxwell EMC chamber
Payload Performance Tests

MIRAS in the Large Space Simulator
NIR and LICEF’s Temperature Profile in the Large Space Simulator

Temperature (°C):
- 10 °C
- 20 °C
- 30 °C
- 35 °C
- 40 °C
- 50 °C
- 60 °C

Hours:
- 0
- 10
- 20
- 30
- 40
- 50
- 60

States:
- nominal
- redundant
Performance over Temperature

NIR Variation over Temperature

\[ V_{kj} = \frac{\sqrt{T_{sys,k} T_{sys,j}}}{G_{kj}} \]

<table>
<thead>
<tr>
<th>NIR Unit</th>
<th>HOT</th>
<th>WARM</th>
<th>HOT</th>
<th>WARM</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB H</td>
<td>0.15</td>
<td>0.22</td>
<td>0.11</td>
<td>0.18</td>
</tr>
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<td>AB V</td>
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<td>0.09</td>
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<tr>
<td>BC H</td>
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<td>0.09</td>
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<tr>
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<tr>
<td>CA H</td>
<td>0.07</td>
<td>0.11</td>
<td>0.04</td>
<td>0.11</td>
</tr>
<tr>
<td>CA V</td>
<td>0.07</td>
<td>0.09</td>
<td>0.02</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Temperature Drift for a 220 K Scene (K/C)

- 10 C → 35 C
- 35 C → 10 C

Specification: < 0.2 K/C; 0.02 K/C with compensation
Performance over Temperature

PMS Variation over Temperature

Range to compute PMS gain sensitivity

$S_G$ mV/K$^\circ$C

Ref PMS gain: $G_{pms}(T_{ph})$ mV/K

Reference PMS gain: $G_{pms}@21^\circ C = G_{pms}@T_{ph} + S_G x (21^\circ C - T_{ph})$
Performance over Temperature

< 0.5 % (1-sigma)

\[ V_{kj} = \sqrt{\frac{T_{sys,k} T_{sys,j}}{G_{kj}}} M_{kj} \]
Performance over Temperature

| \( |G_{kj}| \) Variation over Temperature

\[
V_{kj} = \frac{\sqrt{T_{sys,k} T_{sys,j}}}{G_{kj} M_{kj}}
\]

\(|G_{kj}| < 0.3 \% \text{ pp} \) (worst baseline)

LICEF temperatures (same baseline)
Performance over Temperature

Phase of Gkj and Mkj over Temperature

Arg \{Gkj\} = 16° pp

\[ V_{kj} = \sqrt{\frac{T_{sys,k}}{T_{sys,i}}} \cdot M_{kj} \]
**Performance over Temperature**

Peak-to-peak phase variation of $G_{kj}$ (deg) over temperature

<table>
<thead>
<tr>
<th></th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
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<tr>
<td>H1</td>
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<td>12</td>
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</tbody>
</table>

Peak-to-peak variations within segments are most of them below 0.5° (worst baseline is 1.5°)

$$V_{kj} = \sqrt{\frac{T_{sys,k} T_{sys,j}}{G_{kj}}} M_{kj}$$
LO phase variation tracking (in-orbit calibration)

- requires additional noise injection and Fourier or Spline interpolation;
- to minimise impact on coverage a new 4-epoch calibration sequence is introduced;
Performance over Temperature

Frequency of noise injection to calibrate LO phase variations

- LSS: sampling ×6 the main period is required (i.e. 7.6 min for 45 min period);
- Thermal model prediction for flight: orbital period dominant, thus 1 noise injection / 16 min;
- This frequency TBC during the commissioning phase;
- A reduction of the original short calibration to once a day would keep coverage loss < 1%
Payload Performance Tests

MIRAS in the Maxwell EMC Chamber
NIR sensitivity

<table>
<thead>
<tr>
<th>Radiometric resolution [K]</th>
<th>H</th>
<th>V</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIR AB</td>
<td>0.21</td>
<td>0.21</td>
<td>0.42</td>
<td>0.40</td>
</tr>
<tr>
<td>NIR BC</td>
<td>0.21</td>
<td>0.21</td>
<td>0.44</td>
<td>0.44</td>
</tr>
<tr>
<td>NIR CA</td>
<td>0.19</td>
<td>0.18</td>
<td>0.45</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Specification

| Specification | 0.25 | 0.25 | 0.55 | 0.55 |
Image Validation

NIR Accuracy (using factory values)

Antenna temperature retrieved with factory values (absorbers 293.7 K)

NIR antenna temperature using factory values

7th SMOS Workshop, Frascati, 29-31 October 2007
H-V Correlation Offset (Full-pol Mode)

<table>
<thead>
<tr>
<th></th>
<th>U-corrected offset [cu]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RE</td>
</tr>
<tr>
<td>NIR AB</td>
<td>0.09</td>
</tr>
<tr>
<td>NIR BC</td>
<td>0.54</td>
</tr>
<tr>
<td>NIR CA</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Specification 1
Image Validation

Correlation Offsets (1 cu = $10^{-4}$)

Specification
Relative Phase Recovery
(H-pol)
Other key results found in Maxwell:

- PMS values are stable (gain variation < 0.2% over 12 h);
- Correlations are very stable (<0.5 cu over 12 h);
- Extremely marginal effects of X-band link (in practice, no effect);
- No effects from Star Tracker (with its shielding);
- All measurements show a high degree of consistency;
- All LICEFs are very similar -> highly separable in phase (FwF);
- Dynamic range is above 5 decades (8000 cu – 0.06 cu);
Image Validation

Imaging (Level-1 Processor)

IDEAL

1. same antenna patterns
2. no fringe-washing

\[ T = \text{IHFT}\{V\} \]

\[ T \equiv \frac{T_B - T_r}{\Omega \sqrt{1 - q^2 - \eta^2}} |F_n|^2 \]

\[ V_{kj} \]

G-Matrix

\[ T_B \]
Image Validation

H-pol Modified Brightness Temperature

\[ T = \text{IHFT}\{V\} \]

\[ T \equiv \frac{T_B - T_r}{\Omega \sqrt{1 - \xi^2 - \eta^2}} \left| F_n \right|^2 \]

Time Averaged Temperatures of 94 scenes in the hexagon (H-pol)
Space Average: -5.6202
Space Standard Deviation: 0.24765
Image Validation

Amplification Factor

\[ T \equiv \frac{T_B - T_r}{\Omega \sqrt{1 - \xi^2 - \eta^2}} |F_n|^2 \]
Image Validation

H-pol Brightness Temperature

Time Averaged Temperatures of 94 scenes in the hexagon (H-pol)
Space Average: 287.8785
Space Standard Deviation: 3.3488
Image Validation

H-pol Brightness Temperature in AF-FoV

Time Averaged Temperatures of 94 scenes in the AF-FOV (H-pol)
Space Average: 291.6688
Space Standard Deviation: 0.70352
Image Validation

H-pol Intermediate Radiometric Resolution

Time Standard Deviation of 94 scenes in the hexagon (H-pol)
H-pol Final Image Radiometric Resolution

Time Standard Deviation of 94 scenes in the hexagon (H-pol)

-3 dB beam
4.6 K
boresight
2.3 K
## Error Budget

<table>
<thead>
<tr>
<th>SRD Requirement</th>
<th>System Parameter</th>
<th>Specified Value</th>
<th>SAT-PDR Actual Value</th>
<th>From IVT (IDEAL reconstruction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-4.5.2-002-a,b</td>
<td>Level-1 SM Radiometric Sensitivity 220 K</td>
<td>3.5 K RMS (00)</td>
<td>2.43 K RMS</td>
<td>1.97 K RMS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.8 K RMS (32)</td>
<td>3.98 K RMS</td>
<td>3.94 K RMS</td>
</tr>
<tr>
<td>R-4.5.3-002-a,b</td>
<td>Level-1 OS Radiometric Sensitivity 150 K</td>
<td>2.5 K RMS (00)</td>
<td>1.99 K RMS</td>
<td>1.65 K RMS</td>
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<tr>
<td></td>
<td></td>
<td>4.1 K RMS (32)</td>
<td>3.26 K RMS</td>
<td>3.31 K RMS</td>
</tr>
</tbody>
</table>
Future Work

- Further detailed processing of LSS and IVT
- Validation of the LO calibration sequence
- Consolidation of the in-orbit calibration strategy
- Detailed validation of L1PP
- Empty chamber image of L1PP G-matrix
- Introduction of FTT+Gibbs/SDB Reduction in L1PP
- Performance analysis based on L1PP Maxwell images