Preliminary Evaluation of Passive Thermal Control for the Soil Moisture Active and Passive (SMAP) Radiometer

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SMAP Mission Objectives

- Direct observations of soil moisture and freeze/thaw states from space
- Improved estimates of water, energy and carbon transfers between land and atmosphere
- Enhanced weather and climate forecasts, improved flood prediction and drought monitoring

http://smap.jpl.nasa.gov/

The SMAP mission has not been formally approved by NASA. The decision to proceed with the mission will not occur until the completion of the National Environmental Policy Act (NEPA) process. Material in this document related to SMAP is for information purposes only.
SMAP Team Members and Responsibilities

- Radiometer and ground science data processing (GSFC)
- Radar, instrument integration, test and prelaunch mission management (JPL)
- Reflector boom assembly (Northrop Grumman)
- Spin mechanism assembly (Boeing)
Both fly a GSFC radiometer and JPL radar but:  

**SMAP**  
- Measures soil moisture and freeze/thaw states  
- Single feed horn exposed to the sun  
- Spinning platform  
- 6m deployable spinning antenna  
- 0.6°C/orbit thermal stability requirement  

**Aquarius/SAC-D**  
- Measures sea surface salinity  
- 3 feed horns permanently shadowed  
- Non-spinning platform  
- 2.5m fixed antenna  
- 0.1°C/week thermal stability requirement
- The L-band radar components are on the despun side of SMAP
- The instrument resides on the spun side of the observatory
  - Cylindrical core structure houses Spin Mechanism Assembly (SMA)
  - 3 major assemblies
    - Reflector Boom Assembly (RBA)
    - Integrated Feed Assembly (IFA)
    - Radiometer Back End Assembly (RBEA)
IFA and RBEA are the primary assemblies that make up the L-band radiometer
- RFEA contains the most thermally sensitive components
• RFE is the component with the tightest thermal stability requirement
• MLI cocoon is implemented around the RFEA
  - Isolates components from the environment
Derivation of Thermal Stability Requirements

- An acceptable error was allocated to four time periods
  - Instantaneous per minute rate
  - Change per orbit, month and mission life
Radar and Radiometer shared components

- Shared signal chain

antenna → feed horn → OMT → coupler → diplexer

**Radar:** diplexer → rotary joint → radar electronics located on bus

**Radiometer:** diplexer → RFE → RBE → RDE

- RF dissipation is ~10W and must be accounted for in the RFEA and OMT
### Thermal Requirements

<table>
<thead>
<tr>
<th>Radiometer Component</th>
<th>Zone</th>
<th>Short Term</th>
<th>Long Term</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$dT/dt$ ($^\circ$C/min)</td>
<td>$dT$/orbit ($^\circ$C/orbit)</td>
</tr>
<tr>
<td>RFE</td>
<td>1</td>
<td>0.05</td>
<td>0.6</td>
</tr>
<tr>
<td>Diplexers, CNS, BP Filters, Couplers</td>
<td>2</td>
<td>N/A</td>
<td>1.2</td>
</tr>
<tr>
<td>OMT</td>
<td>3</td>
<td>N/A</td>
<td>2.4</td>
</tr>
<tr>
<td>Isolator &amp; Feedhorn</td>
<td>4</td>
<td>N/A</td>
<td>8</td>
</tr>
<tr>
<td>Radome</td>
<td>5</td>
<td>N/A</td>
<td>120</td>
</tr>
<tr>
<td>RBE</td>
<td>N/A</td>
<td>0.1</td>
<td>N/A</td>
</tr>
<tr>
<td>RDE</td>
<td>N/A</td>
<td>0.5</td>
<td>N/A</td>
</tr>
</tbody>
</table>

- RFE $0.6^\circ$C/orbit requirement is particularly challenging
SMAP orbital parameters
- sun-synchronous 6PM AN orbit
- 685 km altitude
- orbital period is 98.5 minutes
- beta angles range from 58° to 88°
- eclipse when 58° ≤ β ≤ 65°
- max. eclipse time = 18.9 minutes
- no eclipse when 65° ≤ β ≤ 88°
- eclipse event lasts approximately 83 days from May 11 to August 2

* Recommended by Aquarius Thermal Team
SMAP Thermal team and GSFC Coatings Committee agreed to values:

- Includes an addition of 0.05 to Silver Teflon $\alpha$ due to contamination within first 6 months.

### Coating/Material

<table>
<thead>
<tr>
<th>Coating/Material</th>
<th>Solar Absorptivity, $\alpha$</th>
<th>IR Emissivity, $\varepsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silvered Teflon (10mil)</td>
<td>0.09/0.2</td>
<td>0.85/0.82</td>
</tr>
<tr>
<td>Silvered Teflon (5mil)</td>
<td>0.08/0.2</td>
<td>0.81/0.76</td>
</tr>
<tr>
<td>Interior MLI</td>
<td>N/A (never sees sun)</td>
<td>0.1/0.08</td>
</tr>
<tr>
<td>Bare Aluminum</td>
<td>N/A (never sees sun)</td>
<td>0.1/0.03</td>
</tr>
<tr>
<td>Bare Titanium</td>
<td>N/A (never sees sun)</td>
<td>0.18/0.08</td>
</tr>
<tr>
<td>Radome (ESP)</td>
<td>0.20/0.33</td>
<td>0.90/0.7</td>
</tr>
<tr>
<td>Alodine (Chem Film)</td>
<td>N/A (never sees sun)</td>
<td>0.19/0.03</td>
</tr>
<tr>
<td>Clear Anodize (RBE/RDE)</td>
<td>N/A (never sees sun)</td>
<td>0.89/0.66</td>
</tr>
</tbody>
</table>

**Graph:**

- **Silvered Teflon Solar Absorptivity Degradation**

- **Mission Month**

- **Solar Absorptance ($\alpha$)**

- **Graph data points:**
  - Solar Absorptance ($\alpha$) at Mission Month 0 is 0.05.
  - Solar Absorptance ($\alpha$) at Mission Month 10 is 0.20.
  - Solar Absorptance ($\alpha$) at Mission Month 20 is 0.30.
  - Solar Absorptance ($\alpha$) at Mission Month 30 is 0.40.

- **IR Emissivity ($\varepsilon$):**
  - IR Emissivity at Mission Month 0 is 0.85.
  - IR Emissivity at Mission Month 10 is 0.90.
  - IR Emissivity at Mission Month 20 is 0.95.
  - IR Emissivity at Mission Month 30 is 1.00.
<table>
<thead>
<tr>
<th>Steady State Results</th>
<th>Transient Results</th>
<th>Monthly Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>To Size Radiators:</strong></td>
<td><strong>To Assess Short Term Thermal Stabilities:</strong></td>
<td><strong>To assess Mission Life and Monthly Stabilities:</strong></td>
</tr>
<tr>
<td>Worst Case Hot for Science</td>
<td>Worst Stabilities for Science</td>
<td>3 Year Mission Life and Month to Month Thermal Analysis</td>
</tr>
<tr>
<td>• Highest Solar Flux</td>
<td>• Highest Solar Flux</td>
<td>• Solar Flux interpolated from Fig. 8</td>
</tr>
<tr>
<td>• Highest Earth IR</td>
<td>• Highest Earth IR</td>
<td>• Earth IR Flux Interpolated (between 250 W/m² and 190 W/m²) Proportionally to Solar Flux Variation from Fig. 8</td>
</tr>
<tr>
<td>• Highest Albedo Factor</td>
<td>• Highest Albedo Factor</td>
<td>• Nominal Albedo</td>
</tr>
<tr>
<td>• β=89° (No Eclipse)</td>
<td>• β=58° (Maximum Eclipse Duration)</td>
<td>• β interpolated from Fig. 8</td>
</tr>
<tr>
<td>• Nominal ε* = 0.02</td>
<td>• Nominal ε* = 0.02</td>
<td>• Nominal ε* = 0.02</td>
</tr>
<tr>
<td>• CBE + Uncertainty for Dissipations</td>
<td>• CBE + Uncertainty for Dissipations</td>
<td>• CBE + Uncertainty for Dissipations</td>
</tr>
<tr>
<td>• CBE Mass</td>
<td>• CBE Mass</td>
<td>• CBE Mass</td>
</tr>
<tr>
<td>• EOL Optical Properties</td>
<td>• EOL Optical Properties</td>
<td>• EOL Optical Properties</td>
</tr>
<tr>
<td>• S/C Despun Interface Modeled as +40°C Boundary</td>
<td>• S/C Despun Interface modeled as +40°C Boundary</td>
<td>• Optical properties linearly degraded over time to EOL values (includes initial 0.05 increase to ST α value due to contamination)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• S/C Despun Interface Modeled as Time Varying Temperature Boundary</td>
</tr>
</tbody>
</table>
Thermal Design

- Thermal Desktop used to model Instrument
- Signal chain power dissipations varied during design phase
  - Two different thermal designs proposed
Total Dissipation = 17.66 W
Total Mass = 23.71 kg

- **BPFLTR2**
  - 0W
  - 1.12 kg
  - 2.67 W/°C

- **DIPLEXR2**
  - 2.65 W
  - 1.12 kg
  - 4 W/°C
  - 2.67 W/°C X 4

- **PICNICTA**
  - 1.65 kg
  - 2.73 W/°C
  - 6 W/°C

- **COUPLER1**
  - 1.375 W
  - 0.15 kg
  - 2.73 W/°C
  - 8 W/°C

- **RFE**
  - 7.41 W
  - 5.22 kg
  - 2.67 W/°C

- **RFEPTL**
  - 2.06 kg
  - 2.67 W/°C

- **BPFLTR1**
  - 0W
  - 1.12 kg
  - 2.5 W/°C

- **DIPLEXR1**
  - 2.05 W
  - 1.12 kg
  - 2.5 W/°C X 2

- **OMT**
  - 1.5 kg
  - H-Probe (0.915 W), V-Probe (0.915 W)
  - 2.5 W/°C
  - 6 W/°C

- **ISOLATOR**
  - 0.92 kg
  - 6 W/°C

- **FEEDHORN**
  - 5.32 kg
  - 6 W/°C

- **RADOME**
  - 0.46 kg
  - 1.53 W/°C

*For design A: no FERAD, AI ISOLATOR, heavier OMT (2.39 kg)*
Thermal Design Options

Design A

- 10mil Silver Teflon on circumference of feed horn as radiator
- ST MLI (IFA)
- Aluminum Isolator
- Thickened OMT

Design B

- Dedicated front end radiator (10 mil ST)
- Feed horn covered with ST or AK MLI
- Titanium Isolator
- 5mil Silver Teflon or Aluminized Kapton MLI (IFA)
Steady State Results

Design A
0.51 m² radiator

T_max at Diplexer 2

AK MLI Results: RFEA temps increase ~2°C; Feed horn >30°C than ST MLI

Design B with ST MLI
0.065 m² radiator

T_max at RFE

β = 89º hot environment
Orbital Transient Results

Design B AK Transient Results

<table>
<thead>
<tr>
<th>Zone</th>
<th>Component</th>
<th>Design A (°C/min)</th>
<th>Design B ST (°C/min)</th>
<th>Design B AK (°C/min)</th>
<th>Requirement (°C/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RFE</td>
<td>0.14</td>
<td>0.32</td>
<td>0.47</td>
<td>0.6</td>
</tr>
<tr>
<td>2</td>
<td>Diplexer (Picnic Table)</td>
<td>0.16</td>
<td>0.78</td>
<td>0.99</td>
<td>1.2</td>
</tr>
<tr>
<td>3</td>
<td>OMT</td>
<td>0.57</td>
<td>1.22</td>
<td>1.93</td>
<td>2.4</td>
</tr>
<tr>
<td>4</td>
<td>Isolator</td>
<td>4.75</td>
<td>1.42</td>
<td>1.71</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Feedhorn (middle)</td>
<td><strong>18.4</strong></td>
<td>3.91</td>
<td>4.28</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>Radome (outside center)</td>
<td>101</td>
<td>104</td>
<td>99</td>
<td>120</td>
</tr>
</tbody>
</table>

β = 58.5° hot environment

All three cases show large margin against 0.05°C/min requirement (0.008°C/min)

RFE short term reqt.

Design B meets requirements

RFE: 0.47°C/orbit
Diplexer1: 0.92°C/orbit
Coupler1: 0.92°C/orbit
CNS: 0.99°C/orbit

OMT(VP): 1.93°C/orbit
Isolator: 1.7°C/orbit
Feedhorn: 4.3°C/orbit
Design A Monthly Results

Exceeds feed horn short term requirement during eclipse season
Design B ST Monthly Results

Meets all monthly requirements

Nominal environment
• During eclipse season, temperatures drop about 5°C
• Long torturous thermal path from diplexer to feed horn (Design A): \( \Delta T \) from diplexer to OMT(VP) is 10°C
• \( \Delta T \) from diplexer to OMT(VP) is only 3°C for Design B
The short term stabilities of components inside cocoon for design A are better than those of design B.

However, the isolator and feedhorn short term stabilities for design A are much worse than those of design B since the feedhorn is used as radiator for design A.
Orbital variations during last year of mission

- Inversely proportional to beta angle
- Different slopes observed for eclipse and no-eclipse seasons
RFE Monthly Results: Last Year of Mission

- Meets all orbital and monthly stability requirements for all 3 design cases
Feed horn Monthly Results

- Exceeds orbital requirement for Design A
- Design B: using ST MLI makes feed horn temperature colder and monthly stabilities worse compared to results with AK MLI
Mission Life Requirement

- None of 3 designs meets the requirement
- Mitigation Plan
  - Reduce ST EOL $\alpha$ from 0.2 to 0.18
  - Revised Earth IR Flux range of 222 to 243 W/m²

<table>
<thead>
<tr>
<th>Design</th>
<th>Results</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>24.5°C</td>
<td>18°C</td>
</tr>
<tr>
<td>B ST</td>
<td>19°C</td>
<td>12.5°C</td>
</tr>
<tr>
<td>B AK</td>
<td>21°C</td>
<td>14.5°C</td>
</tr>
</tbody>
</table>

Does not meet requirement
## Design B AK Compliance Table

<table>
<thead>
<tr>
<th>Radiometer Component</th>
<th>Zone</th>
<th>Short Term</th>
<th></th>
<th>Long Term</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>dT/dt ( ^\circ \text{C}/\text{min} )</td>
<td>dT/orbit ( ^\circ \text{C}/\text{orbit} )</td>
<td>Monthly ( ^\circ \text{C}/\text{month} )</td>
</tr>
<tr>
<td>Req’t</td>
<td>Predict</td>
<td>Req’t</td>
<td>Predict</td>
<td>Req’t</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>RFE</td>
<td>1</td>
<td>0.05a</td>
<td>0.025+</td>
<td>0.6</td>
</tr>
<tr>
<td>Diplexers, Cal Noise Source, BP Filters, Couplers</td>
<td>2</td>
<td>N/A</td>
<td>N/A</td>
<td>1.2</td>
</tr>
<tr>
<td>OMT</td>
<td>3</td>
<td>N/A</td>
<td>N/A</td>
<td>2.4</td>
</tr>
<tr>
<td>Isolator &amp; Feedhorn</td>
<td>4</td>
<td>N/A</td>
<td>N/A</td>
<td>8</td>
</tr>
<tr>
<td>Radome</td>
<td>5</td>
<td>N/A</td>
<td>N/A</td>
<td>120</td>
</tr>
<tr>
<td>RBE</td>
<td>N/A</td>
<td>0.1b</td>
<td>0.053</td>
<td>N/A</td>
</tr>
<tr>
<td>RDE</td>
<td>N/A</td>
<td>0.5c</td>
<td>0.08+</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Radiometric Budgets \( \leq \): 0.45 K, 2.4 K, 0.8 K

* With IR = 190-250 W/m² as recommended by Aquarius Thermal Team
+ Includes eclipse period, although not required
Conclusion

- Design A meets all short term and monthly stability requirements except the feed horn
  - The feed horn is exposed to the sun to serve as a radiator

- Design B meets all short term and monthly stability requirements utilizing Silver Teflon or Aluminized Kapton exterior MLI surface

- A passive design was developed to meet all temperature and stability requirements
  - A mitigation plan was developed to meet the 15°C mission requirement