Design Overview of the Thermal Control System for the SMAP Mission

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SMAP Project Overview

SMAP is a first-tier mission recommended by 2007 NRC Earth Science Decadal Survey

Primary Science Objectives:
Global, high-resolution mapping of soil moisture and its freeze/thaw state to:
- Link terrestrial water, energy and carbon cycle processes
- Estimate global water and energy fluxes at the land surface
- Quantify net carbon flux in boreal landscapes
- Extend weather and climate forecast skill
- Develop improved flood and drought prediction capability

Mission Implementation:

<table>
<thead>
<tr>
<th>Partners</th>
<th>JPL (project &amp; payload mgmt., science, spacecraft, radar, mission operations, science processing)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>GSFC (science, radiometer, science processing)</td>
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<tr>
<td>Risk</td>
<td>7120.5D Category 2; 8705.4 Payload Risk Class C</td>
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<td>Launch</td>
<td>Oct. 2014, Delta II LV</td>
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<tr>
<td>Orbit</td>
<td>Polar sun synchronous; 685 km (equatorial) altitude, 98 minute orbit</td>
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<td>Duration</td>
<td>3 years</td>
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<td>Payload</td>
<td>L-band (non-imaging) synthetic aperture radar (JPL)</td>
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<td></td>
<td>L-band radiometer (GSFC)</td>
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<td>Shared 6m rotating (14 rpm) antenna (JPL)</td>
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http://smap.jpl.nasa.gov/
Mission Overview

**INSTRUMENT**
- L-band (1.3-GHz) Radar (JPL)
- L-band (1.4-GHz) Radiometer (GSFC)
- Shared antenna (6 m diameter)
- Conical scan: 13–14.6 rpm; 40 incidence
- Continuous 1,000-km swath width

**SPACECRAFT (& RADAR ELECTRONICS)**
- JPL-developed & built
- JPL’s MSAP/MSL avionics, power assys with a small number of new mission-unique card designs
- 1160 kg wet mass (Observatory-level)
- 1100 W capacity (Observatory-level)
- 80 kg propellant capacity
- Commercial space electronics elsewhere

**SMAP Mission Operations & Data Processing**
(JPL, GSFC)

**SCIENCE DATA PRODUCTS**
- Soil Moisture & Freeze/Thaw State Data Products

**Near-Earth Network**

**Surface Validation**

**Mission Design**
- 685-km polar orbit (Sun-sync)
- 8-day repeat ground track
- Continuous instrument operation
- 2- to 3-day global coverage
- 3-year mission duration

**SMAP recently selected Delta II launch vehicle in July ’12**
- Planned launch date: Oct 31, 2014
Mission/Science Driving Requirements

- Two to three day global coverage
  - Drives requirement for conically scanning antenna
- Spatial resolution at 10 km and 3 km for soil moisture and freeze-thaw products
  - Drives 6 meter antenna size, synthetic aperture radar design
- Soil moisture measurement accuracy, including through moderate vegetation
  - Drives requirements for combined active and passive instrument combination
  - Drives the thermal stability requirements for both radiometer and radar
  - Drives requirement for dual polarizations
- Dynamics and control of the scanning antenna to ensure pointing requirements are met while spinning at 14.6 rpm
  - Drives mass properties, antenna optics, spin rate stability/accuracy requirements of the spun instrument
- Characterizing/bounding the terrestrial RFI environment early and ensuring that mitigations are adequate to prevent unacceptable degradation to science data
  - Drives radiometer and radar electronics designs
- Compatibility with existing FAA Radars in shared L-band spectrum allocation
  - Drives radar duty cycle and peak power requirements
Spun Instrument Configuration

**Integrated Feed Assy**
- RFE & Passive RF components mounted to “stacked plate” structure
- Feed Assembly mounted to RFE Plate
- Assembly mounted to core structure using 3 bi-pods

**Cone-Clutch Assembly**

**ICE, RDE, RBE Support Structures**
- ICE and RDE/RBE mounted to separable structures with mounting surface used as radiators

**RBA Launch Restraints**
- Boom Restraint
- Upper Hoop Restraint
- Cradle
- Lower Hoop Restraint

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**Observatory Overview**

**Mission Overview**
- 2- to 3-day global coverage
- 685-km Sun-sync orbit, 6 p.m.

**Observatory Summary**
- 3-axis-stabilized spacecraft, providing momentum compensation for spinning antenna
- Single-string avionics and power control/distribution electronics
- Limited redundancy in ACS sensors and actuators, and telecom radios
- S-band telecom and 130 Mbps science data return via X-band link
- Deployable, fixed solar array
- Hydrazine blowdown propulsion system
- Passive and heater-based thermal control with bus structure serving as radiators

**Combined Instruments**
- L-band (1.26 GHz) Radar
- L-band (1.41 GHz) Radiometer
- Shared antenna (6 m diameter) rotating fixed rate 13 to 14.6 rpm

**Mass**
- Spacecraft: 527 kg (CBE)
- Instrument: 312 kg (CBE)
- JPL DP mass margin: 22%

**Power**
- 1023 W (science mode load), via 3-panel deployable solar array
- 59-Ah BOL battery for launch, eclipse, and other off-Sun modes
- JPL DP power margin: 22%
- Nominal bus voltage: 29.4 – 32.8 V
- Fault bus voltage: 24–29.4 V and 32.8–34 V

**Propellant**
- 80.0 kg usable capacity
- Delta-V: 112.6 m/s (includes contingency)
- Propellant budget: 74.2 kg (includes contingency)
Spacecraft Overview

External Configuration
- Solar arrays are ~8.0 m²
  - Single stage deployment
  - Cell type are triple junction, h = 28%
- 59 A-hr battery outside of -X panel
- Thruster clusters at corners of -Z deck
- Telecom antennas located on outrigger

Internal Configuration
- Highest power instrument radar H/W mounted on -Y panel (anti-sun side, thermally stable)
- Four reaction wheels on mid-deck
- Propulsion tank protrudes into LV separation plane by ~4 inches

Spacecraft is 3-axis stabilized
- +X (direction SC is traveling)
- +Y (direction of sun)
- -Z (direction of earth, nadir)

E Configuration (as of 2/19/2012)
**Instrument Overview**

**Radiometer**
- Provided by GSFC
- Leverages off Aquarius radiometer design
- Includes RFI mitigation (spectral filtering)
- 1400–1427 MHz
- Polarizations: V, H, 3rd & 4th stokes
- 1.3-K accuracy
- 40-km resolution
- 4.3-Mbps data rate

**Common 6-m Spinning Reflector**
- Spin Assembly and Reflector/Boom Assembly derived from heritage designs
  - RBA provided by NGAS-Astro
  - BAPTA provided by Boeing
- Spun structure & thermal from JPL
- Conically scanning at 13–14.6 rpm
- Constant incidence angle of 40-deg

**Radar**
- Provided by JPL
- Leverages off past JPL L-band science radar designs
- 1-MHz chirps tunable over 1217–1298 MHz
- Polarizations: VV, HH, HV
- 500-W SSPA (9% duty cycle)
- 3-km spatial resolution
- 35-Mbps data rate
Spacecraft Thermal Overview

• Simple, inexpensive, low-risk thermal design
  – Mostly passive design features (MLI, radiators supply cold biasing)
  – Electronics conductively coupled to radiator panels
    • CDH / Power panel (-X) = 162 W (CBE)
    • Radar panel (-Y) = 220 W (CBE)
    • GNC / Telecom panel (+X) = 111 W (CBE)
  – MLI coverage optimized to reject electronic heat and conserve survival heater power
  – Some active design features (primary and redundant heater circuits)
    • Most Kapton film heaters controlled via mechanical thermostats
    • FSW controlled propellant line heaters
  – Battery temperature controlled via dedicated radiator/MLI/heaters
    • Externally mounted battery is thermally isolated from SC –X panel
  – Graphite heat spreaders on CDH (-X) panel under high powered H/W
    • K-Core (APG) thermal doubler from Thermacore

• Inst. SIA is mechanically coupled to S/C deck (by design, there is a poor thermal path from instrument to SC)
  – Integrated model assesses SC and instrument thermal performance

• Earth orbiter
  – 685 km altitude
  – 98° inclination (Beta angle = 58° to 89°, max eclipse = 19 min)
SMAP instrument thermal design is challenging and requires frequent interaction with the mechanical team to implement

- Highly variable thermal environment results from fast spinning platform
- Tight thermal stability is critical to success of radiometer
- BAPTA bearing gradient is coupled to the SC top deck temperature

4 thermal enclosures are part of the spun platform; each has a dedicated radiator for proper thermal management

- RFEA (Radiometer Front End Assembly) = 11.0 W (CBE+unc)
- RBEA (Radiometer Back End Assembly) = 62.9 W (CBE+unc)
- ICE = 35.7 W (CBE+unc)
- BAPTA/RJA = 8.24 W (CBE+unc)

Silvered teflon used for radiators to meet temporal stabilities

RFEA and OMT enclosed within an MLI cocoon for better short term stabilities

Active control for RFEA to address gain glitches (control authority range of 15°C)

Feedhorn closed by EPS radome to eliminate sun illumination

Single string survival heater architecture to minimize slip ring usage
Thermal Design Philosophy

• **Maintain a simple, reliable, inexpensive thermal design**
  - Primarily passive design (use radiator/MLI as thermal control surfaces)
  - Most active heaters use mechanical thermostat control for replacement heat
  - Flight software controls external propellant line heaters and RFE heaters

• **Each electronics box conductively coupled to structural panel (doubles as a radiator)**
  - Contact conductances results in 2-5°C gradients between elec boxes and panels
  - Instrument subassemblies each have their own dedicated radiators and replacement heaters

• Must maintain components within Allowable Flight Temperatures (AFTs) per ERD
  - Initial goal was to size radiators to give ~5°C hot-case margin to AFT
  - Thermostat-controlled heaters sized to keep 2°C (redundant heaters) to 5°C (primary heater) margin against cold Op/Non-op AFTs during cold/safe cases

• **MLI blanketing (15 layer) used to block off panel area** on outside of –X, +X, and -Y panels to provide required radiator area
  - MLI blanket properties: $\varepsilon^*_{\text{hot}} = 0.02$ and $\varepsilon^*_{\text{cold}} = 0.05$

• Optical properties
  - \textbf{End-of-life (EOL) for hot cases, Beginning-of-life (BOL) for cold cases}
• Component power dissipations
  • Hot Science: “Science and Telecom” CBE + Contingency from PEL (10-30% contingency for most components)
  • Cold/Safe Mode: 90% of “Science” or “Safe” CBE
    • For Safe Mode - spacecraft is nadir pointed, similar to science orbit
      • Fixed attitude is conservative compared with safe mode rotisserie roll
• Component Mass
  • Use CBE from MEL (less mass is conservative for any stability calculations)
Summary of Thermal Control Hardware

- Kapton film heaters (Tayco)
  - SC uses primary and back-up circuits, with 2 thermostats per heater
    - Flight software controlled heaters on the external propellant line
  - Instrument uses single string survival heaters, with 4 thermostats per heater except RBA heaters
    - SIA operational heaters are powered by ICE
- Thermostats (Honeywell)
  - Thermostats primary turn-on temperature is 3-5C above AFT (with 7C dead-band)
- Thermal sensors (Honeywell/Goodrich PRT or Boeing Thermistor)
  - Use 500, 1000, or 2000 ohm PRT or Boeing thermistor for health & status and active heater control
- APG Doubler/Bracket (K-Core)
  - High conductivity APG used to transfer heat along SC panel
  - Instrument is using it as a highly conductive structural member to support RFEA radiator
- Passive thermal control elements
  - Thermal paints, coating, and isolators use typical JPL parts/processes
  - MLI provides passive isolation from external environment. Typical JPL blankets will be used throughout SMAP
• AutoCad Mechanical 2012 – Create geometry
• Thermal Desktop 5.4 – Calculate radiation exchange factors, describe orbits and calculate heat rates
  • Absorbed flux vs time arrays used for transients (orbital average for any steady state runs)
• Sinda Fluint 5.4 – Calculate temperatures/heat flows
• Temperature trends follow the expected environmental loads (solar / beta inputs and optical property degradation)
• Low beta/long eclipse period results in largest orbital variation
  • Radar panel is most thermally stable (constantly viewing cold space)
• Yearly variations are small compared to 10°C requirement
• Orbital variations are small (1°C) compared to 4°C requirement
Radiometer 3 Year Mission Life

- Modified P control is good enough to meet all stability requirements
  - The design meets stability requirements with passive thermal design
  - ATC used solely to correct for gain glitch temperature set point (has been seen on previous radiometers)

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• Primarily passive thermal control (MLI/thermal control surfaces) provide simple/robust solution
  • Some active components (FSW and mechanical thermostatically controlled heaters) used for survival and operational heaters

• Current work demonstrates that the current thermal design is acceptable and will meet all thermal requirements

• Thermal stability requirements for radar and radiometer are met