Thermal Infrared Earth Resource Monitoring Instrument (THERMI) Size Weight & Power (SWaP) Reduction Study

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Landsat Heritage Performance Requirements

- Earth resource monitoring
  - Measurement of the land surface temperatures in two long-wave infrared bands
- Requirements include spectral, spatial, and radiometry performance
- Requirements driving Size Weight and Power (SWaP)
  - Radiometry
    - Cryogenic operating temperatures
      - Multiple temperature zones
    - On-board calibration system
    - Straylight rejection
  - Spatial resolution
    - Ground sample distance
    - Relative Edge Response (RER) slope
    - RER edge extent

Objective: Minimize SWAP and meet performance requirements
THERMI Overview

• 3 scene select operational modes
  – View Earth
  – View in-flight calibrator
  – View deep space
Focal Plane Module

Driving requirements:
- 60 m GSD
- 185 km swath width
- 2 spectral bands

MCT detector
- Maximize operating temperature (reduce SWaP)
- MCT dark current is highly temperature dependent

MCT performance drives focal plane thermal control
- Minimize temperature to minimize dark current
- Stabilize temperature to minimize dark offset drift (50 mK stability required for 0.5% radiance uncertainty)

25 micron pixels

- 10.8 and 12.0 µm spectral filters bezel-mounted over SCAs

Long linear array of ~3080 detectors
- Multiple overlapping sensor chip assemblies

Sensor Chip Assembly (SCA)
- Readout Integrated Circuit (ROIC)
- 2 wavelength bands (2 sets of 4 X 1024 format)

Four SCAs form one FPA module
- Custom development / adaptation of existing MCT designs
- <1 W power dissipation

<table>
<thead>
<tr>
<th>DETECTOR CHIP</th>
<th>ROIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel pitch</td>
<td>25 µm</td>
</tr>
<tr>
<td>Spectral cutoff</td>
<td>12.9 µm</td>
</tr>
<tr>
<td>QE</td>
<td>40 – 60 %</td>
</tr>
<tr>
<td>Dark current</td>
<td>&lt;1E10 e-/s</td>
</tr>
<tr>
<td>Nonlinearity</td>
<td>&lt; 0.6 %</td>
</tr>
<tr>
<td>Operating Temperature: 70 K</td>
<td></td>
</tr>
</tbody>
</table>
OTA Optical Design

- Aperture 120 mm (F/2.46)
  - Positioned to reduce lens size
- Low emissivity high transmittance materials
- Thermal reject filter tilted 1° to reduce ghosting

- Focal length 295 mm
- FOV 15° X 2°
- Telecentric within 2 degrees
- Uniform F/# across FOV within 0.1

MTF normalized on sampling frequency
- Diffraction
- Detector sampling
- Along track velocity smear
- Jitter
Edge Response Performance Requirements Met with Sharpening

- Relative edge response (RER) analysis includes: diffraction, aberrations, detector sampling, smear along track, jitter
  - Sharpened with low gain 3x3 kernel

- RER requirements are met with sharpening with a slower lens system
  - Overshoot <3% (requirement <5%); Ripple <1% (requirement <5%)

- Benefit of sharpening: RER requirements require 23.6-cm diameter lens with 60 m GSD
  - Larger lens requires ~3X mass, ~4X vol. and ~2X power (compared to 12cm lens)

![Relative Edge Response](image)

![23.6cm Lens Relative SWaP](image)
Stray Light Analysis Predicts Low Impact

- Analysis completed in non-sequential Zemax
- Rays traced from simulated point source to detector
  - Collimated beam at 1° to 89°
  - Azimuthal angles of 0° and 90°
- Scatter off of optical element surfaces due to:
  - Surface roughness
  - Particulate contamination
- Scatter off of baffling and structure

Results: Normalized Detector Irradiance (NDI)

- Predicted stray-light fraction from off-axis earth radian
  - Beginning of life (BOL) 0.06%
  - End of life (EOL) 0.18%

Assumptions
- Off-axis scatter from entire visible earth (64.2° half angle)
- Scene temperature: Target 300 K; Off-axis 330 K
In-Flight Calibration System

- **2-sided Scene Select Mirror (SSM)**
  - Front side flat for normal operation
  - Powered back side mirror reduces IFC from 250 mm diameter to 80 X 15 mm rectangular slit

- **In-Flight Calibrator (IFC)**
  - Hg & Ga phase-change cells provide absolute temperature calibration standards
  - Absolute radiometric uncertainty < 2% (260 K to 330 K)
  - Radiance transfer from high-fidelity (NIST traceable) laboratory blackbody REQUIRED

**Concept of Operation**

- Deep space viewed once per orbit to update dark offset correction
- Calibration source viewed at longer interval to update calibration of individual detector elements
Thermal Management Overview

- **OTA**
  - Cooled to <170 K with passive cold radiator
- **FPA**
  - Active cooling with compact pulse-tube cryocooler to 70 K +/- 50 mK
  - Trim heater control
- **Cold Box**
  - Cryocooler cooled to <80 K
- **Mini Pulse Tube Cryocooler**
  - Coldhead temperature 68 K
  - Lift 1.67 W
- **Housing**
  - Cryocooler heat reject <260 K
- **In Flight Calibrator (IFC)**
  - Controlled at 260 K and 310 K
- **Electronics**
  - Temperatures ~ 290 K, stabilized as required
  - Heat rejected to spacecraft radiators
Thermal Analysis

- THERMI mounts on cryo-radiator panel
- Uses Z93 paint and Vapor Deposited Aluminum (VDA)
- Heat reject window filter reduces OTA parasitic
- Fiber isolation mount reduces FPA parasitic

<table>
<thead>
<tr>
<th>Component</th>
<th>Heat Origin</th>
<th>Heat Rejection Panel</th>
<th>Nominal (W)</th>
<th>Margined (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryocooler Reject</td>
<td>Elect</td>
<td>Cryo-Radiator Stage 1</td>
<td>19.73</td>
<td>23.68</td>
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<tr>
<td>FPA Tape Cable at SS</td>
<td>Parasitic</td>
<td>Cryo-Radiator Stage 1</td>
<td>0.016</td>
<td>0.02</td>
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<tr>
<td>Housing</td>
<td></td>
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<tr>
<td>IFC (Phase Change)</td>
<td>Elect</td>
<td>Cryo-Radiator Stage 1</td>
<td>7.50</td>
<td>9.00</td>
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<tr>
<td>Mirror Motor</td>
<td>Elect</td>
<td>Cryo-Radiator Stage 1</td>
<td>5.80</td>
<td>6.96</td>
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<tr>
<td>OTA Heat Load</td>
<td>Parasitic/Elect</td>
<td>Cryo-Radiator Stage 2</td>
<td>1.74</td>
<td>2.09</td>
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<tr>
<td>Cryocooler Compressor</td>
<td>Elect</td>
<td>Nadir Panel</td>
<td>29.60</td>
<td>35.52</td>
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</table>
Cryo-Radiator Design

• Two-stage cryo-radiator
  – Stage 1 rejects housing heat loads including cryocooler reject power
  – Stage 2 rejects OTA heat loads
  – Stages mounted with thermal isolating structure

• Earth shield
  – Protects Stage 1 and Stage 2 from significant view of earth
  – Minimum beta angle determines canted angle to specularly reflect sunlight away from cryo-radiator

Stage 1 (30”x30”)
Stage 2 (20”x20”)
Earth Shield

Sun
β=17.6° (min)
Earth Shield
(Permanent Shade)
Cryo-Radiator Thermal Predictions

- Stage 1 required to maintain SS housing to bulk-average temperature <260 K
  - With ~243 K operation, Stage 1 maintains the SS housing average temperature ~250 K
- Stage 2 required to maintain telescope <170 K
  - Telescope mount base ~160 K under margined loads
Reductions in SWaP allow THERMI to Fit on a Small Satellite Bus

<table>
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<tr>
<th>Mass with Margin</th>
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<tr>
<td>Payload Electronics</td>
<td>13.1 kg</td>
<td></td>
</tr>
<tr>
<td>OTA</td>
<td>8.3 kg</td>
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<tr>
<td>In Flight Calibrator</td>
<td>6.5 kg</td>
<td></td>
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<tr>
<td>Thermal Management</td>
<td>3.8 kg</td>
<td></td>
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<tr>
<td>Covers and Baffles</td>
<td>6.5 kg</td>
<td></td>
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<tr>
<td>Housing and Mounts</td>
<td>18.6 kg</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>57 kg</strong></td>
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<table>
<thead>
<tr>
<th>Power with Efficiencies and Margin</th>
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<tbody>
<tr>
<td>Payload Electronics</td>
<td>32 W</td>
<td></td>
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<tr>
<td>Thermal Management</td>
<td>76 W</td>
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<tr>
<td>In Flight Calibrator</td>
<td>15 W</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>123 W</strong></td>
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**SSTL-300 Small Satellite Payload Limits**

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<tbody>
<tr>
<td>Power</td>
<td>140 W</td>
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</tr>
<tr>
<td>Mass</td>
<td>300 kg</td>
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<tr>
<td>Volume</td>
<td>60 x 70 x 97 cm</td>
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*SSTL-150 customized for additional power*
Conclusion

- Conformance
  - Predict conformance to Landsat heritage requirements
- SWAP Reduction Efforts
  - MCT SCM selected for higher detector operating temperature
  - Radiator for passive cooling of OTA eliminates need for 2 stage cryocooler
    - Detector cold box shielding allows for hotter OTA
    - Thermal energy reject filter reduces power lift requirement on radiator
  - Optical design to reduce first lens diameter, number of lenses, and OTA length
  - Edge sharpening in software to minimize aperture size and accompanying mass and power
  - SSM focuses light onto one small in-flight calibrator (IFC)
    - Maintain radiometric accuracy using phase change cells
- SWaP reduction allows THERMI to fit on a small satellite bus
- Mission cost historically correlates well with mass and power on-orbit
Acknowledgements

- NASA for funding the study effort
  - Del Jenstrom and his team
- SST-US for choosing SDL as a team member
  - Becky Cudzilo and her team

Thanks!