Central Thermal Bus for Micro and Small Satellites: Scalability and Adaptability

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Introduction

Spacecraft thermal control is emerging as a MAJOR design bottleneck in the future

- New, high power density components
  - Microelectronics
  - Photonics
  - Lasers
  - MEMS

- Decreasing bus volumes
  - Reduces ability to intelligently package electronics components for maximum heat removal efficiency
  - Reduces total heat rejection capacity

- Adaptable design
  - Single solution cold-bias thermal design for all mission envelopes nearly impossible

- Compressed design schedule
- Increased attitude/agility requirements
Introduction

- Small, micro, and nano spacecraft, by nature of purpose, create a feedback loop
  - Intent is to provide a faster means of accessing space
  - Decreases overall program design-build time
  - Increases opportunities for new technology insertion
    - More spacecraft opportunities
    - Less cost-schedule risk
  - New technology often enables further mechanical volume reductions
  - New technology also brings new thermal design issues
Introduction

Central Thermal Bus (CTB) is a Multi-Evaporator Hybrid Loop Heat Pipe

Key Problem: Being able to handle the faster rate of infusion of technologies that dissipate more power while enabling smaller spacecraft.

Solution: Move components to constant temperature baseplates and use a thermal management system that is expandable.

Features of a TMS that will effect a solution to the thermal issues which will plague small spacecraft

- Capability to remove heat from multiple, distributed heat sources
- Heat load sharing
- Variable conductance
- Tight temperature control
- Radiator freeze tolerance
- Miniaturized, scalable components
- High heat flux removal for closely packed components
- Ability to reject or store internal/external heat
- Operability in wide range of external environments and variable sink conditions
- Ability to accommodate multiple sinks from TMS
- Low control power
- Test validated analytical modeling tools
CTB Key Characteristics

- Kim and Edgerton identified the following characteristics as being vital to an effective Central Thermal Bus:
  - Centralized, isothermal mounting platform
  - Physical separation of source and sink
  - Uncoupled structural and thermal design
  - Efficient use of radiator area
  - Scalability to accommodate a wide range of requirements

- The Swales CTB brings the following capabilities to the thermal system toolkit:
  - Heat load sharing via multiple evaporators that can also serve as condensers
  - Scalability by the ability to add evaporators and/or condensers as needed with an almost limitless maximum
  - Multiple Radiators (sinks) enable satellite attitude independence by isolating radiators with insufficient thermal sink and routing vapor to other radiators
CTB Current Status

Small Spacecraft Integrated Thermal Management System (SSITMS)

- Miniaturized CTB, ~ 4kg
- Aimed at small and microsats (150kg, 200W)
- Test bed
  - 4 evaporator test bed developed
  - Evaporator conductance – 5W/°C
  - Tested up to 100W per evaporator
  - 4 freeze-tolerant counterflow condensers
    - Enables simulation of different sink environments to test attitude independence
  - 1W nominal, 8W maximum control heater
    - Controls secondary flow to ensure stable operation
CTB Current Status

- Large Sat Testbed
  - Two, 18 inch evaporators
  - 1kW/evaporator heat removal capacity
  - Expandable to 10 evaporators
Futuresat Systems Study

- Investigation of CTB applicability to 10 different mission profiles
  - Planetary Rover
  - Instrument-to-Orbit piggyback
  - Solar Sentinel heliocentric
  - Inner planet missions
  - Solar polar and high gravity field swingby
  - Outer planet missions
  - Atmospheric entry
  - LEO sun synchronous
  - GEO
  - HEO

- Due to extensive industry experience with LEO orbits, detailed notional mission profile was evaluated to provide context for the CTB
- Swales’ EO-1 mission (launched 11/2000) was considered representative LEO/sun synch “Futuresat” mission and was used to provide a high fidelity evaluation of the CTB (evaluated a redesigned EO-1 with CTB vs. the original cold-bias EO-1 system)
LEO Futuresat Study: Actual EO-1 Configuration

- EO-1 spacecraft is a hexagonal prism, 3 axis stabilized design with an articulating solar array
- Flight thermal design completely cold bias with survival makeup heaters with the exception of the battery bay which was protected from cold side temperatures with the a louver
- Instruments thermally isolated with self contained thermal design
**LEO Futuresat Study: EO-1 with CTB Configuration**

- As-built EO-1 spacecraft bus was modified to incorporate design changes enabled by the CTB
  - Internal components removed from external panels and placed on internal baseplates
  - Baseplates are temperature controlled by CTB evaporators and spreader pipes if needed
  - External panels removed and replaced with MLI
  - Internal baseplates populated on both sides
  - Internal baseplates replace machined stiffeners
LEO Futuresat Study

- Solar array drive panel was retained: Preserved design of array system
- Extended radiator panels added with embedded condensers
- Radiating surface area conserved relative to flight configuration by accounting for both sides of the panels
- Radiator panels may be fixed or deployable depending on launch vehicle constraints
- This design has excess radiator capacity since any exposed surface that can be treated with thermal coating can serve as radiator
Results

- **Mass available to Payload increased to 178kg from 150.4kg**
  - Structural mass reduced by 17kg
    - Could be higher pending structural analysis optimization
  - Wiring harness mass reduced by 14.4kg
    - Components moved closer to data relay hub, center of bus harness interconnect segment, and power supply
  - Elimination of thermal louver removes 1.7kg
  - CTB adds 4.1kg
    - Includes all plumbing, evaporators, condensers, shunts, reservoir and working fluid

- **Power available to Payload increased to 117W from 110W**
  - All thermal control heaters removed.

- **Table 1 on slide 16 shows the complete results**
Other Mission Profiles

♦ Mars Science Lander
  ◇ RTG power sources
    ◇ High heat load overhead
    ◇ Waste heat generation may be used as survival or nocturnal heat source via heat load sharing of CTB
  ◇ Diurnal vs. nocturnal ground conditions
  ◇ High power, small volume motors

♦ Outer Planet Missions
  ◇ RTG Power
    ◇ High heat load overhead
    ◇ Waste heat generation may be used as survival heat source via heat load sharing of CTB

♦ Instrument-to-Orbit
  ◇ Must tolerate wide range of possible orbital environments
  ◇ Minimal architecture tailoring once a specific ride (piggyback) to orbit is found
  ◇ Could also be engineered into a stand alone pallet
    ◇ Accommodate thermal requirements of palletized communications interfaces as well as an instrument
Other Mission Profiles

- **Helio-centric observatories**
  - Wide range of potential orbital environments
  - Use of that CTB offers opportunities to develop common bus which can dynamically adjust to changing thermal sink conditions

- **Highly elliptical orbits**
  - Extreme case of the helio-centric observatory
  - Lessons learned from THEMIS mission
    - Thermal interfacing with instruments extremely difficult to standardize with traditional passive cold bias design
    - CTB would have vastly simplified the process

- **Proximity operations**
  - Highly variable thermal environments
    - Must be able to operate near larger spacecraft
    - May be required to transition from sun side to shadow side of larger spacecraft in a short period of time
    - Must be of small size and relatively low power
  - CTB would enable generic proximity operations bus
Conclusions

- CTB can realize reductions in mass and power on small or micro spacecraft as well as larger spacecraft and rovers

- Pending Futuresat work
  - Optimize radiator surface area based upon analysis
  - Trade component groupings for thermal operation ranges, function, and maximum volume savings
  - Optimize mass reductions using structural analysis
  - Investigate other mission profiles in greater detail
# Table 1  Full Results

<table>
<thead>
<tr>
<th>GEOMETRY</th>
<th>Prior Spacecraft Packaging</th>
<th>Spacecraft Packaging with SSTMS-like Central Thermal &quot;Futuresat&quot; BUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>General S/C Packaging Architecture integrating from Conventional to Central Thermal BUS</td>
<td>![Prior packaging diagram]</td>
<td>![Spacecraft packaging diagram]</td>
</tr>
<tr>
<td>EO-1 S/C Packaging Design integrating from Conventional to Futuresat Central Thermal BUS</td>
<td>![EO-1 packaging diagram]</td>
<td>![Futuresat packaging diagram]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>EO-1 ACTUALS</th>
<th>&quot;FUTURESAT&quot; w/ SSTMS</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEMENT</td>
<td>Mass</td>
<td>Quantity</td>
<td>Total Mass</td>
</tr>
<tr>
<td>Structural Elements</td>
<td>several</td>
<td>varies</td>
<td>79.79</td>
</tr>
<tr>
<td>Wiring Harness Segments</td>
<td>2.4</td>
<td>17</td>
<td>40.88</td>
</tr>
</tbody>
</table>

**Notes:**
- "If EO-1 had used SSTMS" (i.e., "Futuresat")
- Eliminate 3 equip. panels & 3 radial supports; Stiffened remaining 3 equip. panels; Slight lightening of Nadir deck only (stiffer load path from new topology); All other elements unchanged.
- All equipment panels are adjacent via the central junction enabling direct pane-face to pane-face routing (minimizes the "jumper" segments between non-adjacent panels); Same number of circuits.
- SSTMS Internal Elements: 0.3 | 7 | 2.10 | 0.30 | 8 | 2.40 |
- All elements of SSTMS-type Central Thermal Bus excluding external radiator.
- Euplyoxide radiator for SSTMS implementation utilizing both sides for heat rejection (high Tin' efficiency realized).
- Less control zones than EO-1.
- SSTMS Implementation would have enabled 10% more EO-1 payload mass.

<table>
<thead>
<tr>
<th>POWER (Watts)</th>
<th>EO-1 ACTUALS</th>
<th>&quot;FUTURESAT&quot; w/ SSTMS</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEMENT</td>
<td>Power</td>
<td>Quantity</td>
<td>Total Power</td>
</tr>
<tr>
<td>SSTMS Internal Elements</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Bias Heaters</td>
<td>12</td>
<td>1</td>
<td>12.00</td>
</tr>
</tbody>
</table>

**Notes:**
- Secondary evaporator fine control.
- SSTMS Implementation would have enabled 10% more EO-1 payload power.

**Note:** All other satellite components, their associated attachment geometry, and masses remain unchanged in comparison; Same number of circuits & electrical services.
Questions