space structures laboratory

CoreSat Systems Engineering

Fabien Royer
September 11\textsuperscript{th}, 2017
Outline

1) Overview of high level requirements
2) Orbit and lifetime analysis
3) On-orbit maximum power collection
4) Mass budget
5) Communication analysis
6) Mission Scenario
7) Open Issues and Planned Work
High Level Requirements

High level requirement flow-down:

- Subsystem requirements will be presented in dedicated presentations
Lifetime Analysis and Orbit Selection

Potential Scenarios:

1) Boom does not deploy
   - worst configuration: narrow configuration, undeployed, side

2) MirrorSats separations do not occur
   - worst configuration: narrow configuration, side

3) 1 MirrorSat separate and do not redock
   - worst configuration: narrow L, side or tumbling MirrorSat alone

4) 1 MirrorSat separate and redock
   - worst configuration: L configuration, side or tumbling MirrorSat

5) 2 MirrorSats separate and do not redock
   - worst configuration: CoreSat side or tumbling MirrorSat

6) 2 MirrorSats separate and redock
   - worst configuration: I configuration, side
Lifetime Analysis and Orbit Selection

Hypotheses:

- AAReST mass: 24 kg
- Solar cycles and atmospheric density model: Jacchia 1970
- Solar pressure is negligible
- Drag coefficient: 2.2
- Orbit considered: noon/midnight sun-synchronous orbit (worst case for power collection)

Framework:

- Software: AGI STK
Lifetime Analysis and Orbit Selection

Results:

Graph showing the lifetime analysis and orbit selection with various scenarios:
- No boom deployment
- No MirrorSats separations
- No MirrorSat 1 redocking
- MirrorSat 1 redocking
- No MirrorSats redocking
- MirrorSats redocking
- Tumbling MirrorSat alone

The x-axis represents Orbit Altitude (km) ranging from 500 to 570, and the y-axis represents Lifetime (year) ranging from 5 to 30.
Lifetime Analysis and Orbit Selection

Results:

- No MirrorSats separations
- No MirrorSat 1 redocking
- MirrorSat 1 redocking
- No MirrorSats redocking
- Tumbling MirrorSat alone
- Maximum drag configuration

Lifetime (year) vs. Orbit Altitude (km)
Lifetime Analysis and Orbit Selection

Results:
Lifetime Analysis and Orbit Selection

Conclusion:

• Worst case lifetime scenario corresponds to nominal wide configuration:
  ➢ Limit orbit: 560 km altitude

• Mitigation technique to decrease lifetime:
  ➢ Make wide AAResT configuration tumbling at the end of the mission
    Limit orbit for Z axis tumbling: 614 km altitude
    Limit orbit for 3 axes tumbling: 598 km altitude

• Ideal PSLV scenario:
  ➢ Direct launch to 550 km altitude (or less) sun-synchronous orbit (separation before primary payload)
  or
  ➢ Upper stage goes down to 550 km altitude sun-synchronous orbit after launching primary payload
On-orbit Power Collection

Optimal charging phase:

- Altitude: 600 km
- Noon / midnight SSO
- Attitude: Sun pointing (-X)
- Solar panel efficiency: 0.30

Total power: 17.8 W
## Mass Budget

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Component</th>
<th>Max Mass (g)</th>
<th>Contingency (%)</th>
<th>Max Mass + contingency (g)</th>
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</thead>
<tbody>
<tr>
<td>ADCS</td>
<td>Docking Units</td>
<td>1700</td>
<td>20</td>
<td>2040</td>
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<tr>
<td>ADCS</td>
<td>ADCS Stack + Reaction wheels</td>
<td>1106</td>
<td>10</td>
<td>1216.6</td>
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<td>ADCS</td>
<td>Star Camera</td>
<td>166</td>
<td>20</td>
<td>199.2</td>
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<td>ADCS</td>
<td>Payload Interface Board</td>
<td>200</td>
<td></td>
<td>200</td>
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<td>Avionics/Comms</td>
<td>Transceiver</td>
<td>78</td>
<td>10</td>
<td>85.8</td>
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<td>Avionics/Comms</td>
<td>Antenna</td>
<td>100</td>
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<tr>
<td>Power</td>
<td>Solar Panels</td>
<td>520</td>
<td>30</td>
<td>676</td>
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<tr>
<td>Power</td>
<td>EPS + Batteries</td>
<td>675</td>
<td>10</td>
<td>742.5</td>
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<td>Power</td>
<td>Mounting board</td>
<td>270</td>
<td>20</td>
<td>324</td>
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<td>Structures</td>
<td>Chassis</td>
<td>1350</td>
<td>20</td>
<td>1620</td>
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<tr>
<td>Structures</td>
<td>Surface Structural Panels</td>
<td>140</td>
<td>10</td>
<td>154</td>
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<td>Structures</td>
<td>Launch Interface</td>
<td>600</td>
<td>10</td>
<td>660</td>
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<tr>
<td>Structures</td>
<td>Launch Interface plate</td>
<td>860</td>
<td>15</td>
<td>989</td>
</tr>
<tr>
<td>Structures</td>
<td>HDRM - Frangibolts (2 for antennas and 2 for MirrorSats)</td>
<td>400</td>
<td>10</td>
<td>440</td>
</tr>
<tr>
<td>Structures</td>
<td>Circuit Boards (c.6-8)</td>
<td>560</td>
<td>30</td>
<td>728</td>
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<tr>
<td><strong>Core Sat Total</strong></td>
<td><strong>8725</strong></td>
<td><strong>8907.1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wiring</td>
<td></td>
<td>436</td>
<td>30</td>
<td>566.8</td>
</tr>
<tr>
<td><strong>From January 2017</strong></td>
<td><strong>Total System Mass</strong></td>
<td><strong>23561</strong></td>
<td></td>
<td><strong>24507.1</strong></td>
</tr>
</tbody>
</table>

Contingency scale:
- 0 = verified
- 10 = COTS
- 15 = COTS + fab
- 20 = fab only
- 30 = very rough
Communication Link Budget

Data Budget:

- Max data rates:
  - UHF: 9.6 kbps
  - VHF: 1.2 kbps
- Downlink over UHF required (435 – 438 MHz)
- Assume 8 min passes; max. time between passes is 10 hrs.
- Docking video taken and downlinked over several passes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Health data [kbps]</th>
<th>Ops data [kbps]</th>
<th>Data rate required for single pass [kbps]</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>0.31</td>
<td>0</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td>Debug</td>
<td>8.86</td>
<td>0</td>
<td>8.86</td>
<td></td>
</tr>
<tr>
<td>Docking data</td>
<td>0.31</td>
<td>0.27</td>
<td>0.58</td>
<td>ADCS and health data</td>
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<tr>
<td>Star imaging</td>
<td>0.31</td>
<td>1.4*</td>
<td>1.71</td>
<td>2 windowed SHWS images, 1 windowed star image</td>
</tr>
<tr>
<td>Earth/Moon imaging</td>
<td>0.31</td>
<td>5.1*</td>
<td>5.41</td>
<td>PNG image (no windowing)</td>
</tr>
</tbody>
</table>

* Computed from image size from flight detectors
Communication Link Budget

Hypothesis:

**AAReST side**

- Focus on UHF downlink: 438 MHz
- Data rate: 9.65 Kbps
- Antenna modeled as dipole: 0.17 m length
- Modulation scheme: FSK
- -X face pointing at the Sun
- Noon/night sunsynchronous orbit

**Ground Station side**

- Single ground station Guildford, UK
- 2.5 m diameter antenna
- Tracking AAReST
- System noise temperature: 135 K
- 85° cone visibility

**Framework:** AGI STK
Communication Link Budget

Access intervals:

Statistics over 1 year

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Max duration</td>
<td>14.1 min</td>
</tr>
<tr>
<td>Min duration (min)</td>
<td>0.15 min</td>
</tr>
<tr>
<td>Average duration (min)</td>
<td>10.8 min</td>
</tr>
<tr>
<td>Average passes per day</td>
<td></td>
</tr>
</tbody>
</table>
Communication Link Budget

Access intervals (one day):

- 4 h 40 min (fluctuates)
- 1 h 38 min
- 10h (fluctuates)
Communication Link Budget

Link Margin:

- Carrier to noise ratio desired: 10 dB
- Transceiver input power: 0.8 W
- Bit error rate less than $10^{-10}$
- Average carrier to noise ratio: 15.4 dB
Mission Scenario

Nominal Mission Chronology

3 h 45 mn (2 orbits)
- Detumble AAREST
  - Operate ADCS to detumble AAREST

2 h to 6 h
- Charge batteries and MirrorSats
  - Orientate AAREST in its optimal charging attitude
  - Send beacon message every 3 mn
  - Turn on camera and check imaging detector and shackle-Hartman wf sensor
  - Turn off camera and test high voltage line to mirror electrodes
  - Send health data, telescope data at first access with ground station, and boom inspection camera images

5 h 34 mn (3 orbits) 4 passes
- Take first image and check ADCS requirements
  - Point AAREST to calibration star (ex Polaris)
  - Image calibration star with reference mirrors
  - Send 2 windowed SHWS images, 1 windowed star image, and health data
  - Image calibration star with all mirrors in narrow configuration
  - Send 2 windowed SHWS images, 1 windowed star image, and health data

4 h to 10 h
- Charge batteries and MirrorSats
  - Orientate AAREST in its optimal charging attitude
  - Send beacon message every 3 mn
  - Send health data at first access with ground station

5 h 34 mn (3 orbits) 4 passes
- Take image in compact configuration
  - Point AAREST to science star (ex Sirius or Betelgeuse)
  - Image science star in narrow configuration
  - Send 2 windowed SHWS images, 1 windowed star image, and health data
  - Repeat pointing and imaging procedure above for Earth imaging and Moon imaging
  - Send png image of Earth and Moon and health data
Mission Scenario

**Nominal Mission Chronology**

1. **4 h to 10 h**
   - Charge batteries and MirrorSats
     - Orientate AAReST in its optimal charging attitude
     - Send beacon message every 3 mn
     - Send health data at first access with ground station

2. **5 h 34 mn (3 orbits) 4 passes**
   - Perform reconfiguration preparation for Mirror Sat 1
     - Actuate MirrorSat 1 frangibolt
     - Undock MirrorSat 1
     - Redock MirrorSat 1 on the same CoreSat face
     - Record maneuver with boom inspection camera and send images
     - Point AAReST to science star (ex Sirius or Betelgeuse)
     - Image science star in narrow configuration
     - Send 2 windowed SHWS images, 1 windowed star image, and health data

3. **3 h 45 mn (2 orbits)**
   - Detumble AAReST
     - Operate ADCS to detumble AAReST

4. **2 h to 6 h**
   - Charge batteries and MirrorSats
     - Orientate AAReST in its optimal charging attitude
     - Send beacon message every 3 mn
     - Send health data at first access with ground station

5. **3 mn (up to 5 mn) up to 4 passes**
   - Perform reconfiguration maneuver for Mirror Sat 1
     - Undock MirrorSat 1, drift and stop 332 mm away
     - Carry out 76.2° CoreSat rotation and capture MirrorSat 1
     - Send live telemetry and health data
     - Record maneuver with boom inspection camera and send images

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Mission Scenario

**Nominal Mission Chronology**

- **3 h 45 mn (2 orbits)**
  - **Detumble AAREST**
    - Operate ADCS to detumble AAREST
  - **Charge batteries and MirrorSats**
    - Orientate AAREST in its optimal charging attitude
    - Send beacon message every 3 mn
    - Send health data at first access with ground station

- **2 h to 6 h**
  - **Take image in L configuration**
    - Point AAREST to science star (ex Sirius or Betelgeuse)
    - Image science star in wide configuration
    - Send 2 windowed SHWS images, 1 windowed star image, and health data
    - Repeat pointing and imaging procedure above for Earth imaging and Moon imaging
    - Send png image of Earth and Moon and health data

- **5 h 34 mn (3 orbits) 4 passes**
  - **Charge batteries and MirrorSats**
    - Orientate AAREST in its optimal charging attitude
    - Send beacon message every 3 mn
    - Send health data at first access with ground station

- **4 h to 10 h**
  - **Charge batteries and MirrorSats**
    - Orientate AAREST in its optimal charging attitude
    - Send beacon message every 3 mn
    - Send health data at first access with ground station

- **5 h 34 mn (3 orbits) 4 passes**
  - **Perform reconfiguration preparation for MirrorSat 2**
    - Actuate MirrorSat 2 frangibolt
    - Undock MirrorSat 2
    - Redock MirrorSat 2 on the same CoreSat face
    - Point AAREST to science star (ex Sirius or Betelgeuse)
    - Image science star in narrow configuration
    - Send 2 windowed SHWS images, 1 windowed star image, and health data
Mission Scenario

**Nominal Mission Chronology**

1. **3 h 45 mn (2 orbits)**
   - **Detumble AAREST**
     - Operate ADCS to detumble AAREST
   - **Charge batteries and MirrorSats**
     - Orientate AAREST in its optimal charging attitude
     - Send beacon message every 3 mn
     - Send health data at first access with ground station

2. **2 h to 6 h**
   - **Perform reconfiguration maneuver for MirrorSat 2**
     - Undock MirrorSat 2, drift and stop 419 mm away
     - Carry out 71° CoreSat rotation and capture MirrorSat 2
     - Send live telemetry and health data
     - Record maneuver with boom inspection camera and send images

3. **3 mn (up to 5 mn) up to 4 passes**
   - **Detumble AAREST**
     - Operate ADCS to detumble AAREST

4. **4 h to 10 h**
   - **Take image in wide configuration**
     - Point AAREST to science star (ex Siriu or Betelgeuse)
     - Image science star in wide configuration
     - Send 2 windowed SHWS images, 1 windowed star image, and health data

5. **5 h 34 mn (3 orbits) 4 passes**
   - Repeat pointing and imaging procedure above for Earth imaging and Moon imaging
   - Send png image of Earth and Moon and health data

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Mission Scenario

Docking Maneuver:

1. Narrow configuration

2. 332 mm

3. 76.2°
   180 mm
   + MirrorSat climb up

4. L configuration

5. 419 mm

6. 273 mm
   71°
   + MirrorSat climb up

7. Wide configuration
Open Issues and Planned Work

Open issues:

• Need to develop docking maneuver requirements
• Need to develop complete CONOPS documentation

Planned work

• Develop Integrated STK model for full mission scenario simulation
• Develop (and revisit) full AAReST integration and testing
space structures laboratory

AAReST Attitude Determination and Control (ADC) System Design

Michael Marshall
September 11th, 2017
Outline

• **Design overview**
  • Driving requirements
  • Operational modes
  • Additional requirements
  • Primary design criteria
  • ADCS architecture block diagram
  • Overview of CubeSpace ADCS
  • Requirements Verification

• **ADCS Integration and Interfaces**

• **Future Work**
Driving Requirements

**Detumble:**

- Reduce body angular rates $< 0.3^\circ$/s in 4 orbits or less

**Science:**

- Pointing accuracy – error $< 0.1^\circ$ $3\sigma$ per axis
- Attitude stability – jitter $< 0.02^\circ$/s $3\sigma$ for 600s during science operations

**Rendezvous and Docking (RDV):**

- Rotate $90^\circ$ in 60s about boom axis

MS = MirrorSat

1. Stowed

2. Narrow

3. 1 MS narrow, 2$^{nd}$ free

4. 1 MS narrow, 2$^{nd}$ wide

5. 1 MS free, 2$^{nd}$ wide

6. Wide
Operational Modes

- **Ground Testing**
  - **Idle**
  - **Detumble (Safe)**

- **Rendezvous and Docking (RDV)**
  - **Science (Fine Pointing)**
  - **Sun Pointing (Coarse Pointing)**

- **Ground Track**

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caltech.edu  11 September 2017  AAReST ADCS
Operational Modes – Safe Mode ACS Flow

Ground Testing

Idle

Detumble (Safe)

Slew

Rendezvous and Docking (RDV)

Science (Fine Pointing)

Sun Pointing (Coarse Pointing)

Ground Track

Safe Mode ACS Flow
Overlap with Mission Chronology

ADCS Operational Modes

Launch

Deployment from Launch Vehicle

Turn ON Subsystems

Verify and Stabilize Satellite

Idle

Detumble

Boom Deployment

Telescope Calibration

Science Operations in Narrow Configuration

Execute RDV Maneuver for 1st MirrorSat

Coarse Pointing

Fine Pointing

Fine Pointing

Rendezvous and Docking (RDV)

Science Operations in Wide Configuration

Extended Mission

Execute RDV Maneuver for 2nd MirrorSat

Fine Pointing

Rendezvous and Docking (RDV)
## ADCS Generated Requirements

<table>
<thead>
<tr>
<th>Operational Mode</th>
<th>Additional Requirements</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Testing</td>
<td>• n/a</td>
<td>• n/a</td>
</tr>
<tr>
<td>Idle</td>
<td>• n/a</td>
<td>• n/a</td>
</tr>
<tr>
<td>Detumble (Safe)</td>
<td>• n/a</td>
<td>• n/a</td>
</tr>
<tr>
<td>Slew</td>
<td>• Reorient spacecraft to within 1° of desired attitude</td>
<td>• Required to change operational mode</td>
</tr>
<tr>
<td>Rendezvous and Docking (RDV)</td>
<td>• n/a</td>
<td>• n/a</td>
</tr>
<tr>
<td>Science (Fine Pointing)</td>
<td>• n/a</td>
<td>• n/a</td>
</tr>
<tr>
<td>Sun Pointing (Course Pointing)</td>
<td>• Maintain attitude within ± 10° of optimal charging angle</td>
<td>• Maximize power generation</td>
</tr>
<tr>
<td>Ground Track</td>
<td>• Maintain commanded antenna orientation with TBD degrees</td>
<td>• Maintain proper antenna orientation during pass</td>
</tr>
<tr>
<td>All</td>
<td>• Have capability to desaturate reaction wheels</td>
<td>• Required to maintain control of spacecraft</td>
</tr>
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</table>
Primary Design Criteria

• Meets system and ADCS requirements

• Integrated solution that includes all sensors, actuators, and software

• Reaction wheels with sufficient torque and angular momentum storage to:
  • Execute z-axis slew maneuver for RDV
  • Reject worst-case disturbance torques during science operations (with continuous momentum dumping from torque rods)

• Low cost, (relatively) short lead time

• Solution: CubeSpace 3-Axis ADCS w/Star Tracker
Overview of CubeSpace 3-Axis ADCS

- Integrated 3-axis ADCS capable of providing accurate and precise pointing for CubeSats
- Advertises pointing and estimation accuracies in excess of $0.1^\circ \ 3\sigma$ per axis (during eclipse with star tracker)
  - Lower performance in sun
- Includes ADCS software and CubeComputer OBC
- Flight heritage for most components (via QB50)
- 5 month lead time
CubeSpace 3-Axis ADCS Components

- **Includes:**
  - CubeComputer – radiation tolerant on-board computer (OBC) that doubles as AAReST OBC
  - CubeControl – sensor and actuator interface board w/3-axis rate gyros
  - CubeSense – fine earth and sun sensors
  - 3x Large CubeWheels – mounted separately from stack on orthogonal body axes
  - 10x coarse sun sensors – for coarse attitude determination (e.g. during detumbling)
  - 2x CubeTorquer Rods + 1x CubeTorquer Coil – magnetic torque rods for detumbling and momentum desaturation
  - CubeStar – star tracker for quaternion and angular rate estimation during fine pointing/science operations
ADCS Architecture

- Fine Earth Sensor
- Sensor PCB (CubeSense) [Star Tracker (CubeStar)]
- Fine Sun Sensor
- To Other Subsystems

ADCS Computer

- 3-Axis Magnetometer
- 3-Axis Rate Gyro
- Actuator PCB (CubeControl)
- 3x Magnetic Torque Rods (CubeTorquer)
- 10x Coarse Sun Sensors
- 3x Reaction Wheels (CubeWheel – Large)
ADCS Sensors

- **CubeStar** – star tracker
  - $3\sigma$ estimation accuracy - $0.03^\circ$ $3\sigma$ yaw/pitch, $0.09^\circ$ roll (about boresight)
  - Typically averages 3-10 star vector measurements per second using Extended Kalman Filter (EKF)

- **CubeSense** – fine Earth and sun sensors
  - Earth sensor $1\sigma$ estimation accuracy – $0.1^\circ$ (with full earth in FOV)
  - Sun sensor $1\sigma$ estimation accuracy – $0.1^\circ$

- **CubeControl** – MEMs rate gyros
  - 10 milli-deg/s RMS noise

- **Magnetometer**
  - $0.5^\circ$ RMS accuracy in roll, pitch, yaw
ADCS Actuators

- Large CubeWheel – reaction wheels
  - Speed range ±6000 rpm
  - Maximum torque – 2.3 mN-m
  - Maximum angular momentum storage – 30.7 mN-m-s
  - 220g/wheel

- CubeTorquer – magnetic torque rods
  - 0.4 A-m² saturation magnetic moment
Requirements Verification Overview

- Developed Simulink tool to analyze ADCS performance in each operational mode

- Conducted Monte Carlo analyses to assess ADCS performance over a wide range of attitudes
  
  - Typically consider 100 random attitudes in a nominal 550 km sun-synchronous orbit
  
  - Consider all *relevant* spacecraft configurations (but will only present representative results from a single configuration)
  
  - Analyses conducted to assess pointing accuracy and stability and system’s capability to desaturate reaction wheels, all during science operations

- Separate analysis to show feasibility of z-axis slew maneuver for RDV
Requirements Verification Tool

- Dynamics
  - 2 body orbit dynamics
  - Full 3D nonlinear Euler equations for rotational motion
  - Quaternions for attitude propagation
  - Reaction wheel model with static and dynamic imbalances
  - Simple magnetorquer model
  - Models for gravity gradient, magnetic and drag disturbance torques
Requirements Verification Tool (cont.)

• Control
  • B-dot detumble controller
  • Momentum dumping controller
  • Nonlinear PD controller (slew, trajectory tracking, pointing)

• Estimation
  • Rate gyro model
  • Star tracker model
  • Kalman filter (fine pointing)
  • Extended Kalman filter (EKF)
Pointing Accuracy and Stability Analysis

• Applicable requirements:
  • Pointing accuracy – error < 0.1° 3σ per axis
  • Attitude stability – jitter < 0.02°/s 3σ for 600s (10 min) during science operations

• Assumptions:
  • Inertially-fixed attitude (to simulate science operations)
  • Modeling dominant environmental disturbance torque (gravity gradients), reaction wheel disturbances, process noise
  • Estimated dynamics (from Kalman filter – estimate attitude and angular velocity from star tracker measurement)

• Results shown for wide configuration
Pointing Accuracy – Wide, Wide
Pointing Stability – Wide, Wide

\[ \omega_x (\circ/s) \]

\[ \omega_y (\circ/s) \]

\[ \omega_z (\circ/s) \]

\[ \mu \]

\[ \mu + 3\sigma \]

\[ \mu - 3\sigma \]

Requirement
Camera Frame Visualization - Slewing

![Graph showing pointing error over time for Roll, Pitch, Yaw, and Total.](image)
Camera Frame Visualization - Slewing

video @ 10x actual
Camera Frame Visualization - Pointing

![Graph showing pointing error over time for Roll, Pitch, Yaw, and Total with time in minutes on the x-axis and pointing error in degrees on the y-axis. The graph indicates a stabilization of pointing error over time.]
Camera Frame Visualization - Pointing

video @ 10x actual
Desaturation Analysis

- Applicable requirement: ADCS shall have the capability to desaturate the reaction wheels

- Assumptions:
  - Continuous desaturation with magnetic torque rods (max magnetic moment 0.4 A-m²)
  - Inertially-fixed attitude (to simulate science operations)
  - Modeling dominant environmental disturbance torque (gravity gradients), reaction wheel disturbances
  - Truth dynamics

- Results shown for *wide* configuration
Z-Axis Slew Maneuver

• Applicable requirement: rotation 90° in 60s about boom (z) axis

• Assumptions:
  • Idealized slew maneuver – no disturbances, noise, etc.
  • Truth dynamics

• Maneuver simulated open-loop via precomputed control trajectory

• Takeaway: z-axis slew maneuver completed in 60 seconds with large angular momentum margins
Z-Axis Slew Analysis – Empty, Narrow

[Graphs showing angular velocity, angular acceleration, reaction wheel angular momentum, and reaction wheel control torque over time.]
Z-Axis Slew Analysis – Wide, Empty
## Requirements Verification Matrix

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement Met?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Detumble:</strong></td>
<td></td>
</tr>
<tr>
<td>• Reduce body angular rate &lt; 0.3°/s in 4 orbits or less</td>
<td>Yes*</td>
</tr>
<tr>
<td><strong>Science:</strong></td>
<td></td>
</tr>
<tr>
<td>• Pointing accuracy – error &lt; 0.1° 3σ per axis</td>
<td>Yes**</td>
</tr>
<tr>
<td>• Attitude stability – jitter &lt; 0.02°/s 3σ for 600s during science operations</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Rendezvous and Docking (RDV):</strong></td>
<td></td>
</tr>
<tr>
<td>• Rotate 90° in 60s about boom axis</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>All</strong></td>
<td></td>
</tr>
<tr>
<td>• Have capability to desaturate reaction wheels</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Preliminary results  
**Some caveats
ADCS Integration into CoreSat

• CubeComputer, CubeSense, and CubeControl in central PC104 stack
  • Fine earth and sun sensors mounted separately from CubeSense board

• 3x Large CubeWheels (reaction wheels) located near center of mass in central stack, mounted on orthogonal body axes
  • Mechanical interfaces TBD

• Star tracker mounted to maximize field of view (FOV) given other constraints (e.g. optical system)

• Interfaces over I2C
(Notional) ADCS Interfaces Diagram

Note: all interfaces are over I2C

Legend:
- Primary
- Secondary
- Other

3x CubeWheel - Large
Samtec Header

CubeControl
PC104 Header

CubeSense
PC104 Header

CubeComputer
PC104 Header
Piggyback Header

CubeStar (Star Tracker)
HARWIN L-Tek Header

To 10x Coarse Sun Sensors

To Other Subsystems
Future Work

- Detailed (Monte Carlo) detumble analysis
- Higher fidelity z-axis slew maneuver simulation
- Quantification of pointing constraints (e.g. star tracker cannot be pointed at the sun)
- Algorithm for real-time execution of z-axis slew maneuver?
- Hardware acquisition
- Component testing
- Subsystem integration, assembly, and testing
Open Issues/Discussion Topics

- ConOps during rendezvous and docking (RDV) maneuver (including z-axis slew maneuver)
- Docking system magnetic modeling
  - Updates/models for remnant magnetic moments, torques on spacecraft during RDV, etc.
Backup Slides
Notes on Gravity Gradient Torques

• Largest disturbance torque acting on AAReST by 1+ orders of magnitude

• For a given orbit, maximum gravity gradient torque is proportional to maximum difference between principal inertias
  • $T_{gg,\text{max}} = \frac{3\mu}{2r^3} |J_{xx} - J_{zz}| \approx 15 \mu N - m$

• Function of attitude relative to orbit and inertias

• Independent of roll
Note on Gravity Gradient Torques (cont.)

- Approximately 1/3 of sky with $T_{gg} > 0.75 T_{gg,max}$
Pointing Accuracy and Stability Analysis – Additional Results
Pointing Accuracy – Empty, Narrow
Pointing Stability – Empty, Narrow

\[\begin{align*}
\omega_x (\text{rad/s}) & \quad \omega_y (\text{rad/s}) & \quad \omega_z (\text{rad/s}) \\
\hline
\mu & \mu + 3\sigma & \mu - 3\sigma \\
\text{Requirement} & & \\
\end{align*}\]
Pointing Accuracy – Narrow, Narrow
Pointing Stability – Narrow, Narrow

![Graphs showing pointing stability measurements for different run numbers.]
Pointing Accuracy – Wide, Empty
Pointing Stability – Wide, Empty

\[
\begin{array}{c}
\omega_x (\degree/s) \\
\omega_y (\degree/s) \\
\omega_z (\degree/s)
\end{array}
\]

- \( \mu \)
- \( \mu + 3\sigma \)
- \( \mu - 3\sigma \)
- Requirement

Run #
Desaturation Analysis – Additional Results
Desaturation Analysis – Empty, Narrow

- Polar Angle vs. Azimuthal Angle
- Reaction Wheel Angular Momentum vs. Time
- Torque Rod Magnetic Moment vs. Time
- Torque Rod Control Torque vs. Time

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Desaturation Analysis – Narrow, Narrow

---

11 September 2017

AAReST ADCS

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Desaturation Analysis – Wide, Empty

- Polar Angle (°)
- Azimuthal Angle (°)
- Reaction Wheel Angular Momentum (mN·m)
- Torque Rod Magnetic Moment (A·m²)
- Torque Rod Control Torque (mN·m·s)

11 September 2017
AAReST ADCS
Desaturation Analysis – Wide, Narrow

- Polar Angle (°)
- Azimuthal Angle (°)
- Reaction Wheel Angular Momentum (mN-m/s)
- Torque Rod Magnetic Moment (A-m²)
- Torque Rod Control Torque (mN-m/s)

caltech.edu  11 September 2017   AAReST ADCS
space structures laboratory

AAReST CoreSat Power System

Ashish Goel
Chris Bradley
Charlie Dorn
Juliane Preimesberger
Outline

• Power sub-system requirements
• Power budget
• Proposed solution
  • Solar cells
  • EPS and batteries
  • Solar panel mounting and fabrication
  • Power generation and depth of discharge analysis
  • System diagram with voltages and currents
• Interfaces
• Outstanding issues/concerns
Power Sub-System Requirements

- Provide sufficient power to all subsystems in all operating modes for proposed mission lifetime of 6 months
- Meet nominal, peak and inrush current requirements of all components
- Provide up to 5 W of power to MirrorSats (5V, 1A)
- Provide sufficient power for frangibolt (28 V, 0.9 A) and burn wire (~2 V, 2.5 A) actuation
- Solar panels must accommodate coarse sun sensors, thermistors and not interfere with the docking process
- Solar cell arrangement must deal with likelihood of shadowing from the boom and other deployables
- Batteries must carry sufficient capacity to power the satellite during detumbling phase
- Batteries must incorporate heaters to keep them within operating temperature range (0-40 C)
- EPS must incorporate safety inhibits (RBF), kill switch and separation detection switches
# Power Budget

<table>
<thead>
<tr>
<th>Operating mode</th>
<th>Power</th>
<th>Actuator</th>
<th>Nominal</th>
<th>Ground comm</th>
<th>Science</th>
<th>Docking</th>
<th>Mirrorsat Charging</th>
<th>Battery heating</th>
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<td></td>
<td>Burn wire</td>
<td>Detumble release</td>
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<td>Boom Deployment</td>
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<td>Camera</td>
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<td></td>
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<td>Total Power (W)</td>
<td>9.51</td>
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<td>Total Power with 30% Margin (W)</td>
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<td>9.76</td>
<td>30.40</td>
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<td>5 V bus peak current (A)</td>
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<td>Max Mode Duration</td>
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<td>&lt; 2 orbits</td>
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<td>&lt; 8 min</td>
<td>&lt; 10 min</td>
<td>2 min</td>
<td>&lt; 4 hours</td>
<td>5 min</td>
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</tbody>
</table>

Good estimate
Subject to change
EPS – GomSpace NanoPower P60

- **P60 dock**
- **Array conditioning unit (ACU)**
  - 6 PV input channels
  - 16 V, 2A max per input
  - Individual MPPT on each input
  - Current and voltage measurements on each input
- **Power distribution unit (PDU)**
  - 9 switchable, overcurrent protected outputs
  - All outputs through PC 104 header, 6 outputs also through discrete connector
  - 1-2 A programmable current limits (not PC104)
  - Current, voltage and overcurrent diagnostics on each output
## Solar Cell Selection

- **Commercial panels vs in-house**
- **Coverglass Interconnected Cell options (includes tabs, bypass diode)**

<table>
<thead>
<tr>
<th></th>
<th>Efficiency</th>
<th>Surface area (cm²)</th>
<th>Lead time (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrolab XTJ Prime</td>
<td>30.7%</td>
<td>27.2</td>
<td>3-4</td>
</tr>
<tr>
<td>Spectrolab UTJ</td>
<td>28.3%</td>
<td>26.6</td>
<td>5-6</td>
</tr>
<tr>
<td>Azurspace 3G30A</td>
<td>29.3%</td>
<td>30.2</td>
<td>8-12</td>
</tr>
</tbody>
</table>

![Spectrolab XTJ Prime](image1.png)  
![Spectrolab UTJ](image2.png)  
![Azurspace 3G30A](image3.png)
Solar Cell Selection

- Commercial panels vs in-house
- Coverglass Interconnected Cell (CIC) options

<table>
<thead>
<tr>
<th></th>
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<tr>
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<td>29.3%</td>
<td>30.2</td>
<td>8-12</td>
</tr>
</tbody>
</table>

Spectrolab XTJ Prime

Spectrolab UTJ

Azurspace 3G30A

27cm² Class (Rectangular Cell)
Panel Assembly Procedure

- Modified CU Boulder procedure
- Fabricated and tested three functioning panels
- Finalized procedure steps:
  - Cut tabs
  - Laser cut double-sided Kapton tape
  - Vacuum bagging
  - Solder and add conductive epoxy
Panel Testing

Illumination

<table>
<thead>
<tr>
<th></th>
<th>Pre-assembly</th>
<th>Post-assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell A</td>
<td>6.7 mA, 0.51 V</td>
<td>9.7 mA, 0.63 V</td>
</tr>
<tr>
<td>Cell B</td>
<td>5.3 mA, 0.79 V</td>
<td>10.6 mA, 0.78 V</td>
</tr>
<tr>
<td>Solar panel</td>
<td>-</td>
<td>11.37 mA, 1.46 V</td>
</tr>
</tbody>
</table>

Electroluminescence

Vacuum

IR imaging

Void
Solar Cell Placement: +X Face

General approach: Place cells wherever possible, even undesired orientations

- Fine sun sensor/nadir sensor
- Docking port
- Frangibolt

Not shown
- Coarse sun sensors
- Thermistors
Solar Cell Placement: -X Face

- Antenna mount
- Fine sun sensor/nadir sensor
- Hole for passing nichrome wire

Assumption: -X panel will be removed for tensioning the frangibolts during integration in India
Solar Cell Placement: +/-Y Face

Not shown/unknown
- LIDAR/LEDs/Optical camera for docking
- Access panel

<table>
<thead>
<tr>
<th></th>
<th>-X</th>
<th>+X</th>
<th>-Y</th>
<th>+Y</th>
<th>RMB</th>
<th>Total</th>
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<tbody>
<tr>
<td></td>
<td>23</td>
<td>23</td>
<td>7</td>
<td>7</td>
<td>12</td>
<td>72</td>
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</table>
**Total Power Available**

<table>
<thead>
<tr>
<th>Orientation</th>
<th>CoreSat OAP (W)</th>
<th>Total OAP (W)</th>
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</thead>
<tbody>
<tr>
<td>Narrow optimal (θₓ=27.4°)</td>
<td>25.7</td>
<td>29.5</td>
</tr>
<tr>
<td>Wide optimal (θₓ=0°)</td>
<td>24.6</td>
<td>33.8</td>
</tr>
<tr>
<td>Detumble</td>
<td>7.9</td>
<td>12.3</td>
</tr>
</tbody>
</table>

1. Noon-midnight sun synchronous orbit, 600 km
2. Temperature, design and assembly-related losses: 20%
3. BOL numbers due to short mission duration

Optimum angle \( \theta_x = atan \left( \frac{A_y}{A_x} \right) \)
Battery Selection

• GomSpace NanoPower BPX
  • 77 Whr
  • 500 g
  • Integrated heater
  • 8 weeks lead time
Depth of Discharge Analysis

- GomSpace BPX battery (77 Whr) provides sufficient storage
- Detumbling mode is the largest strain on the battery
Solar Cell Wiring Schematic

Possible shadowing due to folded antennas, boom
Inefficient wiring of shadowed cells leads to large power losses

- P60 EPS
  - Inputs < 16V, 2A
  - 2.7V, 0.5A per cell

Input 1
- 13.5 V, 1.5 A

Input 2
- 10.8 V, 1.5 A

Input 3
- 8.1 V, 1.0 A

Input 4
- 8.1 V, 0.5 A

No shadow
Antenna shadow, good wiring
Antenna shadow, inefficient wiring

[Diagram of solar cell wiring schematic]

Graph showing power (W) vs voltage (V)

Caltech
Pre-Launch Interface from Gomspace

- USB charging
- CAN Interface to communicate with
  - EPS
  - BPX battery
- Battery voltage sensing pins
- RBF pins, kill switch
- Board dimensions: 32 mm X 32 mm
Inhibit Scheme (Separation Detection)

P60 Dock

K.S.

2 DPDT switches in series
Unresolved Issues/Future Work

- MirrorSat charging interface
- Dimensions and locations of docking-related sensors
- Number and location of separation switches
- Functionality of payload switchboard
- Location of access port
- Finalizing cabling scheme
- PC104 header compatibility checks
Thank you

Questions?
CoreSat Structures

Christophe Leclerc
Mélanie Delapierre
Federico Bosi

September 11 2017
Outline

1. CoreSat Design
   • Requirements
   • Structural Design
   • Internal Configuration
   • Interfaces

2. FEM: Launch Survivability
   • Model Description
   • Results

3. Future Work
Main Structural Requirements

• Withstand launch environment, with critical acceleration of 11 g
• Natural frequencies must be higher than (TBC):
  • 90 Hz (longitudinal mode)
  • 45 Hz (lateral mode)
• Provide accurate positioning of optical systems:
  • Mirror boxes
  • Boom support
  • Docking ports
• Provide mechanical support for all subsystems
• Use CubeSat standards for subsystem components (96 mm x 96 mm PCBs)
• Provide vertical clearance of 50 mm for MirrorSat docking maneuvers
CoreSat Structural Design

**Design Guidelines**
- Flexibility for components positioning
- Optical calibration independent of internal assembly
- Flexible clearance at the bottom

Frame Breakdown:
- Top frame
- Corner rails
- Internal module
- +X face
- -X face
- Bottom frame
- LVI plate
- LVI ring
- Boom support (-X face)
- Mirror Box
- Side stiffener
Internal Module Assembly

- Mount internal components in CubeSat standard PCBs
- Group internal components in modules
- Modules are mounted between $+X$ and $-X$ faces contributing to the stiffness and stability of the CoreSat

Example: Power system

Modular design allows for modules to be assembled, tested, and replaced individually

PCBs with CubeSat standards (96 x 96 mm)

Spacer (15 mm)

Example: Power system

Internal frame

CAD source: Gomspace
Optical System Assembly

1. -X face
   - Top and bottom frames

2. Add docking ports

3. Add corner rails

4. Add remaining optical system
   - Optical system can be aligned independently of other subsystems
Complete Assembly

- Add LVI plate
- Add side components
- Add central components
- Close +X face and stiffeners (with solar panels)
- Add solar panels

Modular design allows for flexibility in assembly

Structure
Optical system
Other components

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CG Location (Launch)

21 mm (in front of the CoreSat)

249.2 mm

8 mm (from the center of the LVI)
LVI Adapter Plate

- Indian Space Research Organisation (ISRO) IBL230 separation device used in PSLV
  - CoreSat must attach to this ring
- Dimensions and properties
  - 8 M6x1 mounting holes, clearance on ring
  - Pitch Circle Diameter (PCD) of 230 mm
  - 0.6 kg retained on satellite after separation

Part of ring that remains on launch vehicle after separation

Image Source: IBL230 datasheet
LVI Adapter Plate

- Must withstand peak accelerations during launch without failure (yield)
- Must place center of mass (COM) of AAReST in its stowed configuration over center of LVI ring
- Should utilize all 8 mounting holes on LVI ring
- Should distribute launch loads evenly
  - Concentration of loads in one location could result in failure

![Diagram of LVI Adapter Plate]

- Estimated location of COM
- LVI Ring
- CoreSat
- Mirror Sat
- 100 mm
- 300 mm
- 230 mm
LVI Adapter Plate

- Parameters: 25g steady, 27kg, yielding 505MPa (preliminary study done with NASA standard)
- Latest mass: 980g
- Safety factor 2+ (except at screws)
- Loading at CG: 6 directions + corner
List of Components

- ADCS
- Reaction wheels
- Power
  - EPS
  - Batteries
- HDRM
  - MirrorSats separation devices (x2)
  - Camera separation device
- Docking ports
- Star camera
- Sun sensor (x2)
- Payload Interface Computer (x3)
- Interface board (x3)
- Antenna release mechanism (x2)
- Radio transceiver

Priority for Central Stack:
1. HDRM (camera)
2. Wheels
3. Payload Interface Computer
4. Components using PC/104 (ADCS and EPS)
5. Batteries
6. Transceiver

Other decision drivers:
- Optical alignment
- CG management
- PIC should be close to the mirror boxes
- Sun sensors and star camera must have sufficient field of view
- (Thermal management)
Positioning of Components

- Docking ports
- HDRM
- Antenna release mechanism
- LVI plate
Positioning of Components

- Docking ports
- Reaction wheels
- Antenna release mechanism
- HDRM
- Antenna release mechanism
- ADCS boards
- EPS
- Batteries
- LVI plate
Positioning of Components

- Star camera
- Sun sensor (+X)
- Payload Interface
- Computers and interface boards (x3)
- Docking ports
- Reaction wheels
- Antenna release mechanism
- Antenna release mechanism
- Sun sensor (-X)
- LVI plate
- HDRM
- Antenna release mechanism
- ADCS boards
- EPS
- Batteries
Positioning of Components

- Star camera
- Sun sensor (+X)
- Payload Interface
- Computers and interface boards (x3)
- Docking ports
- Reaction wheels
- Antenna release mechanism
- Sun sensor (-X)
- Radio transceiver
- LVI plate
- HDRM
- Antenna release mechanism
- ADCS boards
- EPS
- Batteries
- Antenna fixations
Interfaces

• The CoreSat has deployable interfaces with 2 components:
  • MirroSats
  • Camera

• A study led to the selection of the TiNi FC2 Frangibolt as the Hold Down and Release Mechanism (HDRM) for both types of separation
  • Compatible with power system
  • Sufficient load capacity
  • Small enough to integrate inside the current design
TiNi FC2 Frangibolt

- Standard way of using a Frangibolt is with a single cup and cone interface

Separation occurs at the interface, where there is a notch in the bolt
TiNi FC2 Frangibolt

- A new architecture was designed to integrate the Frangibolt in the CoreSat
- Release load: 4 448 N
TiNi FC2 Frangibolt
Almost all the preloading is here (cup & cone)

Soft spacers for stability

Preload with the nut

Bolt head is held by cap
Interface to MirrorSats

Goal:
- Preload docking ports for launch, gap needed at HDRM
- Contact at HDRM for release loading
Open Issues

- Location of the separation switch
- Can we have anything reaching through the LVI ring?
Open Issues

• Unknown location/dimensions of some subsystems (ADCS, docking ports, flight preparation panel, sensors for docking, etc.)
• Is there LIDAR on the CoreSat?
• Interface between CoreSat and MirrorSat
  • The preloading scheme must be improved
  • We must verify that the stored energy will not eject the MirrorSats
Launch Survivability Analysis

- Static loading at maximum accelerations
- Focus on CoreSat frame
### FEM Model in Abaqus/Standard

#### Properties

<table>
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<th>Material</th>
<th>Density (Kg/m³)</th>
<th>Poisson’s ratio</th>
<th>Young’s Modulus (GPa)</th>
<th>Yield point (MPa)</th>
<th>Requirement (von Mises (MPa))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>2700</td>
<td>0.34</td>
<td>70</td>
<td>240</td>
<td>120</td>
</tr>
<tr>
<td>Delrin</td>
<td>1420</td>
<td>0.34</td>
<td>2.4</td>
<td>62</td>
<td>31</td>
</tr>
</tbody>
</table>

#### Failure criteria

- Requirement (von Mises (MPa))
Docking Mount & Frangibolt Models

- Frangibolt:
  - Load carried by Delrin “cantilever”
  - Or
  - Docking mount: Delrin
  - Frangibolt plate: rigid
FEM Model in Abaqus/Standard

CoreSat frame
1 part, aluminum

Rigid frangibolt plates
Delrin docking mounts

Point masses

<table>
<thead>
<tr>
<th>Element</th>
<th>Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM box</td>
<td>*2 821.33</td>
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<tr>
<td>Camera</td>
<td>2735.19</td>
</tr>
<tr>
<td>Mirror Sat + DM boxes</td>
<td>*2 4447.63</td>
</tr>
<tr>
<td>ADCS+reaction wheels</td>
<td>1105.68</td>
</tr>
<tr>
<td>EPS+batteries</td>
<td>674.81</td>
</tr>
<tr>
<td>Docking units</td>
<td>*4 424.21</td>
</tr>
<tr>
<td>Star camera</td>
<td>165.9</td>
</tr>
<tr>
<td>Antennas</td>
<td>*2 99.97</td>
</tr>
</tbody>
</table>

Frame Mass= 3,477 g
Total Mass = 20,357 g
Mass Attachments to CoreSat

MirrorSat:
- Distributing coupling on 5 surfaces
- No pre constraints

Camera:
- Distributing coupling on 4 surfaces

Other masses:
- Distributing coupling on 4 surfaces
Results: von Mises Stress Distribution

von Mises (Pa)

Aluminum Yield Point

<table>
<thead>
<tr>
<th>Stress Level (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1.200e+08</td>
</tr>
<tr>
<td>+1.100e+08</td>
</tr>
<tr>
<td>+1.000e+08</td>
</tr>
<tr>
<td>+9.000e+07</td>
</tr>
<tr>
<td>+8.000e+07</td>
</tr>
<tr>
<td>+7.000e+07</td>
</tr>
<tr>
<td>+6.000e+07</td>
</tr>
<tr>
<td>+5.000e+07</td>
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<tr>
<td>+4.000e+07</td>
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<tr>
<td>+3.000e+07</td>
</tr>
<tr>
<td>+2.000e+07</td>
</tr>
<tr>
<td>+1.000e+07</td>
</tr>
<tr>
<td>+3.424e+02</td>
</tr>
</tbody>
</table>

Delrin Yield Point

Clamped

6 g  6 g

11 g

caltech.edu
Updated Design

- Additional brackets
- Filled bottom holes
- Front frame thickness from 1mm => 2 mm
- Updated docking mount
Results: von Mises Stress Distribution

- Added mass in frame ~ 174 g
- Meets the requirements
Future Work

• Finalize internal configuration
  • Substitute the actual subsystems
  • Add all missing elements
  • Design internal structures for wheels

• Solve the interface issues (MirrorSats and Camera)

• Detailed model of MirrorSat and Camera attachment to CoreSat in FEM

• Finalize the structural design

• Integrate the separation switch inside the design

• Manufacturing, integration and testing
space structures laboratory

AAReST Communications

Antonio Pedivellano
Eduardo Placentia
Maria Sakovsky

The content of these slides is preliminary or provisional and is subject to revision. Not for general distribution.
Communications Requirements

1. Comms must use VHF/UHF amateur frequency band
2. Antennas should minimize required pointing for comms
3. Antennas should minimize losses
4. Transceiver must be COTS and conform to CubeSat form factor
5. Transceiver must not interface over I2C
6. Must be able to downlink live telemetry (ADCS and health data) during separation and docking
7. Must be able to downlink the following data:
   a) Critical health data since last pass
   b) 2 SHWS images, 1 science image during science ops
   c) Full earth/moon images
Outline

1. Data Budgets
2. Component Selection
3. EM Simulations
4. Design and Test
Outline

1. Data Budgets
2. Component Selection
3. EM Simulations
4. Design and Test
Data Budget – Nominal Operations

- Spacecraft and instrument health variables recorded every 5 mins for nominal operation

- Health data since last pass downlinked
  - Worst case: 8 min pass to downlink 10 hrs of data (max time between passes)

- Total health data = 150.72 kb/pass; data rate = 0.31 kbps

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Component</th>
<th># of sensors</th>
<th># measurements /pass</th>
<th>Data rate [kb /pass]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera</td>
<td>Temperature</td>
<td>6</td>
<td>720</td>
<td>5.76</td>
</tr>
<tr>
<td></td>
<td>State Variables</td>
<td>4</td>
<td>480</td>
<td>3.84</td>
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<tr>
<td>Def mirrors</td>
<td>Voltages</td>
<td>82</td>
<td>9840</td>
<td>78.72</td>
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<tr>
<td></td>
<td>Temperatures</td>
<td>10</td>
<td>1200</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td>Picomotors</td>
<td>6</td>
<td>720</td>
<td>5.76</td>
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<tr>
<td>Ref mirrors</td>
<td>Temperatures</td>
<td>2</td>
<td>240</td>
<td>1.92</td>
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<tr>
<td></td>
<td>Picomotors</td>
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<td>720</td>
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<tr>
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<td>720</td>
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<td></td>
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<td>360</td>
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<td>EPS</td>
<td>Solar Panels Voltages</td>
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<td>720</td>
<td>5.76</td>
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<tr>
<td></td>
<td>Solar Panel Currents</td>
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<td>720</td>
<td>5.76</td>
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<td></td>
<td>Battery voltages</td>
<td>2</td>
<td>240</td>
<td>1.92</td>
</tr>
<tr>
<td></td>
<td>Battery currents</td>
<td>2</td>
<td>240</td>
<td>1.92</td>
</tr>
</tbody>
</table>
Data Budget – Reconfiguration

- ADCS readings at 1 Hz for 8 min pass + health data
- Total maneuver data = 128.55 kb/pass; data rate = 0.27 kbps

<table>
<thead>
<tr>
<th>Class</th>
<th>Component</th>
<th># of sensors</th>
<th>Frequency [#/hr]</th>
<th># measurements /pass</th>
<th>Data rate [kb/pass]</th>
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<tbody>
<tr>
<td>Camera</td>
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<td>9.6</td>
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<td>9.6</td>
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<tr>
<td>Ref mirrors</td>
<td>Temperatures</td>
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<td>3.2</td>
<td>0.0256</td>
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<td>12</td>
<td>9.6</td>
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<td>Rates</td>
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<td>3600</td>
<td>1440</td>
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</tr>
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<td>Temps</td>
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<td>12</td>
<td>9.6</td>
<td>0.0768</td>
</tr>
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<td>Temperature sensors</td>
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<td>12</td>
<td>8</td>
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<td>ADCS</td>
<td>Quaternions</td>
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<td>3600</td>
<td>1920</td>
<td>30.72</td>
</tr>
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<td></td>
<td>Rates</td>
<td>3</td>
<td>3600</td>
<td>1440</td>
<td>23.04</td>
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<td>Sensors</td>
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<td>3600</td>
<td>2400</td>
<td>19.2</td>
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<td>EPS</td>
<td>Solar Panels Voltages</td>
<td>6</td>
<td>12</td>
<td>9.6</td>
<td>0.0768</td>
</tr>
<tr>
<td></td>
<td>Solar Panel Currents?</td>
<td>6</td>
<td>12</td>
<td>9.6</td>
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<td></td>
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<td>2</td>
<td>12</td>
<td>3.2</td>
<td>0.0256</td>
</tr>
</tbody>
</table>
Data Budget

- **Max data rates:**
  - UHF: 9.6 kbps - downlink
  - VHF: 1.2 kbps - uplink

- Assume 8 min passes; no overhead included
- Docking video taken and downlinked over several passes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Health data [kbps]</th>
<th>Ops data [kbps]</th>
<th>Data rate required for single pass [kbps]</th>
<th>Total Data Size (kBytes)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>0.31</td>
<td>0</td>
<td>0.31</td>
<td>19</td>
<td>ADCS and health data</td>
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<tr>
<td>Docking data</td>
<td>0.31</td>
<td>0.27</td>
<td>0.58</td>
<td>35</td>
<td>2 windowed SHWS images, 1 windowed star image</td>
</tr>
<tr>
<td>Star imaging</td>
<td>0.31</td>
<td>1.4*</td>
<td>1.71</td>
<td>103</td>
<td>PNG image (no windowing)</td>
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<tr>
<td>Earth/Moon imaging</td>
<td>0.31</td>
<td>5.1*</td>
<td>5.41</td>
<td>325</td>
<td></td>
</tr>
</tbody>
</table>

* Computed from image size from flight detectors
Outline

1. Data Budgets
2. Component Selection
3. EM Simulations
4. Design and Test
Transceiver Selection

- All options are compatible with CubeSat form factor and have SMA/MCX connections for antenna
- Astrodev helium radio is the top choice due to low cost and UART interface

<table>
<thead>
<tr>
<th>Product</th>
<th>Cost</th>
<th>Mass (g)</th>
<th>Max Downlink Bit Rate (kbps)</th>
<th>Bus Interface</th>
<th>Data Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>AstroDev Helium Radio</td>
<td>+</td>
<td>78</td>
<td>9.6</td>
<td>UART</td>
<td>AX.25, HDLC</td>
</tr>
<tr>
<td>ClydeSpace CPUT VUTRX</td>
<td>++</td>
<td>90</td>
<td>9.6</td>
<td>I2C (UART/CAN @ extra $)</td>
<td>AX.25</td>
</tr>
<tr>
<td>ISIS UHF Down/VHF Up Transceiver</td>
<td>++</td>
<td>75</td>
<td>9.6</td>
<td>I2C</td>
<td>AX.25, HDLC</td>
</tr>
</tbody>
</table>
Transceiver Selection

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<td>75</td>
<td>9.6</td>
<td>I2C</td>
<td>AX.25, HDLC</td>
</tr>
</tbody>
</table>
Astrodev Helium Radio

- **Modulation:** FSK

- **Power**
  - Output transmit power: 100 mW – 7W
  - Power usage: receive < 200 mW; transmit < 16 W

- **Interfaces**
  - Input voltages: 3.3 V logic; 5-13 V transceiver
  - Serial interface: 3.3 V UART

- **Mechanical**
  - Operating temperature: -30 – 70°C
  - CubeSat form factor
  - MCX connectors at right angle

- **Sold with breakout board, software to configure radio**
Antenna Type Tradeoff

- **COTS solutions unreliable in deployment**
- **Design considerations**
  - Large beamwidths
  - Large gains
  - Ease of packaging/deployment
  - Size
- **Monopole antenna selected**
  - Small, easy to deploy solution
  - Acceptable electromagnetic performance
  - Common solution for CubeSats

**Monopole**
- **Pros**: good gain, cheap, easy to manufacture
- **Cons**: Linear polarization, ground plane required

**Dipole**
- **Pros**: good gain, no ground plane
- **Cons**: very long

**Crossed monopoles**
- **Pros**: cross polarization
- **Cons**: space limitations

**Inverted F monopole**
- **Pros**: compact, easily tunable
- **Cons**: Less efficient than monopole, difficult to deploy

**Helical antenna**
- **Pros**: circular polarization
- **Cons**: Quite massive, difficult to manufacture

**Spiral antenna**
- **Pros**: Circular polarization
- **Cons**: Large, difficult to manufacture
Antenna Positioning

- Antennas mounted on –Z face at corners
  - +Z (mirror boxes)
  - +/-Y, +X (reserved for MirrorSat docking)
  - -X face (reduces space available for solar panels)

- Electromagnetic analysis required to understand effect of LVI ring
Outline

1. Data Budgets
2. Component Selection
3. EM Simulations
4. Design and Test
Antenna Electromagnetic Simulations

• **Software:** CST Student Edition
  • max 30,000 elements

• **Model elements:**
  • CoreSats, MirrorSats, mirror boxes, camera: 1 mm thick Al shells
  • LVI ring: Al cylinder
  • Boom: carbon fiber; isolated from spacecraft
  • Antenna: steel, tape measure profile
    • 50 Ω discrete ports
  • Entire spacecraft used as RF ground
  • Narrow configuration

• **Missing from model:** cutouts in boom and chassis

• **Simulation parameters:**
  • Antenna length + angle
VHF Antenna Performance

- Performance metric: reflection coefficient $s_{11} < -10$ dB
- Presence of boom significantly affects antenna performance
- $0^\circ$ configuration (antennas point along z-axis)
  - Boom resonates at $\lambda$ corresponding to $L/2$
- Boom resonance not seen in $90^\circ$ configuration
VHF Antenna Performance

- Radiation pattern (145 MHz) for tuned antenna length (L)

- Expected radiation pattern is doughnut shaped around antenna axis
  - LVI ring tilts axis of doughnut
  - Presence of boom results in additional lobes
VHF Antenna Performance – 90° Configuration

- 90° antenna configuration closest to expected performance
- Deviation from theory due to ring, boom, and finite ground plane
- Radiation pattern shows good gains (2.83 dB) and large beamwidths (~90°)

Y-Z Plane

X-Y Plane

Frequency = 145 MHz
Main lobe magnitude = 2.81 dB
Main lobe direction = 34.0 deg.
Angular width (3 dB) = 69.0 deg.

Frequency = 145 MHz
Main lobe magnitude = 0.969 dB
Main lobe direction = 196.0 deg.
Angular width (3 dB) = 98.5 deg.
UHF Antenna Performance

- Performance metric: reflection coefficient $s_{11} < -10$ dB
- No boom resonance seen in desired UHF downlink frequency
- Performance in $90^\circ$ configuration wideband
VHF Antenna Performance

- Radiation pattern (365.5 MHz) for tuned antenna length (L)
- UHF radiation pattern significantly affected by LVI but not boom
  - Effects of LVI minimized in 90° configuration
  - 0° configuration has a significant number of addition lobes
UHF Antenna Performance – 90° Configuration

- 90° antenna configuration closest to expected performance
- Deviation from theory due to ring, boom, and finite ground plane
- Radiation pattern shows good gains (4.2 dB) and large beamwidths (∼55°)

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EM Simulations Summary

• Antenna performance deviates from theoretical doughnut shape
  • LVI and finite ground plane tilts pattern and introduces extra lobes
  • Boom resonates at VHF when parallel to antennas

• Best performance seen in 90° configuration

• VHF operation
  • S11 ~ -40 dB at 46 cm length, 145 MHz
  • Close to expected monopole radiation pattern
  • Gain = 2.83 dB; 3-dB Beamwidth = ~90°

• UHF operation
  • S11 ~ -20 dB at 14.6 cm length, 436.5 MHz
  • Close to expected monopole radiation pattern with additional side lobes
  • Gain = 4.2 dB; 3-dB Beamwidth = ~55°
Outline

1. Data Budgets
2. Component Selection
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4. Design and Test
Antenna Folding Sequence

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Deployment Mechanism Design

- **Connection to CoreSat**: epoxy filled slot to hold antenna
  - Isolates antenna from ground (chassis)

- **One release mechanism per antenna (reused from mirror boxes)**

- **Vectran wire restrains each antenna against launch vibrations**
  - Threaded through holes in antennas to prevent antenna sliding during launch

- **Non-conductive spacers between antenna and -X face of CoreSat**
  - Preserve functionality in case of failed deployment

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Antenna Structural Testing

- **Test setup built with ISIS 3U CubeSat Kit and waterjet panels**

- **Test plan**
  - Mechanical design check
  - Deployment reliability
  - Launch vibration survivability
Deployment Testing

- Antenna tested with CubeSat positioned vertically (deployment against gravity) and horizontally
  - 2 A, 1.2 V; deployment ~ 12 s
  - 3 tests total, successful deployment in all cases
- Tests will be repeated to verify repeatability of antenna deployment trajectory
Antenna Electrical Connections

• Objective: test connection reliability

• Procedure:
  • Sand paint from antenna
  • Tin the PCB and inner face of antenna with solder
  • Using kapton tape, tape PCB and antenna assembly on hot plate
  • Stack weights on assembly
  • Heat at 200°C for 15 min

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Electromagnetic Test Plan

- **Build representative model**
  - CoreSat chassis, mock LVI, COTS MirrorSats, boom, camera

- **Antenna length tuning**
  - Reflection coefficient measurements using network analyzer on campus

- **Radiation pattern measurements**
  - Measurements with power meter

- **EM compatibility testing**
Summary and Open Issues

• **Subsystem specs:**
  • Downlink over UHF, uplink over VHF
  • Astrodev Helium transceiver
  • Deployable monopole antennas

• **Subsystem analysis:**
  • UHF sufficient to transmit health data, debug data, and camera images in a single 8 min pass
  • 90° configuration minimizes boom interference
    • VHF and UHF radiation patterns close to theoretical
    • Acceptable gains and wide beamwidths
  • Antenna structural design complete and testing in progress

• **Open issues**
  • Boom interference with antenna performance
  • Vibration testing
  • Frequency allocation
space structures laboratory

Combined Simulation Data

9/10/17
Overall model – VHF, no boom + camera

- text
Overall model – VHF, with boom + camera

Frequency = 145 MHz
Main lobe magnitude = 2.34 dB
Main lobe direction = 91.0 deg.
Angular width (3 dB) = 81.7 deg.

Frequency = 145 MHz
Main lobe magnitude = 2.36 dB
Main lobe direction = 100.0 deg.
Overall model – VHF, with boom + camera

- text

![Graph showing S11 (dB) vs Frequency (MHz) for different lengths L: L = 46 cm, L = 47 cm, L = 48 cm, L = 49 cm. The graph indicates resonances with dips at certain frequencies.]
Overall model – VHF, with boom + camera

Frequency = 145 MHz
Main lobe magnitude = 3.17 dB
Main lobe direction = 108.0 deg.
Angular width (3 dB) = 50.0 deg.
Side lobe level = -1.3 dB

Frequency = 145 MHz
Main lobe magnitude = 1.4 dB
Main lobe direction = 84.0 deg.
Angular width (3 dB) = 313.4 deg.
Overall model – UHF, no boom + camera

- text

![Graph showing S11 (dB) vs Frequency (MHz) for different L values, with labels indicating L = 14.4, 14.6, 14.8, and 15 cm, with a narrow frequency range highlighted.]

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Overall model – UHF, no boom + camera

Frequency = 436.5 MHz
Main lobe magnitude = 2.52 dB
Main lobe direction = 131.0 deg.
Angular width (3 dB) = 240.6 deg.
Side lobe level = -2.6 dB

Frequency = 436.5 MHz
Main lobe magnitude = 0.901 dB
Main lobe direction = 91.0 deg.
Angular width (3 dB) = 311.0 deg.
Overall model – UHF, with boom + camera

- text
Overall model – UHF, with boom + camera; 14.6 cm

The content of these slides is preliminary or provisional and is subject to revision. Not for general distribution.
Overall model – VHF, 90 deg

- text

![Graph showing S11 (dB) vs Frequency (MHz) for different values of L (46 cm, 47 cm, 48 cm, 49 cm). The graph is labeled "Narrow" and shows a resonance peak at 150 MHz with a depth of approximately -10 dB.](image-url)
Overall model – VHF 90 deg

Frequency = 145 MHz
Main lobe magnitude = 2.81 dB
Main lobe direction = 34.0 deg.
Angular width (3 dB) = 69.0 deg.

Frequency = 145 MHz
Main lobe magnitude = 0.969 dB
Main lobe direction = 196.0 deg.
Angular width (3 dB) = 98.5 deg.

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Overall model – UHF, 90 deg

- text

![Graph showing S11 (dB) vs Frequency (MHz) for different values of L: L = 14.4 cm, L = 14.6 cm, L = 14.8 cm, L = 15 cm. The graph includes a dashed line at S11 = -10 dB.](image)
Overall model – UHF 90 deg 14.6 cm

- Frequency = 436.5 MHz
- Main lobe magnitude = 4.1 dB
- Main lobe direction = 4.0 deg.
- Angular width (3 dB) = 55.3 deg.
- Side lobe level = -1.2 dB

- Frequency = 436.5 MHz
- Main lobe magnitude = 0.515 dB
- Main lobe direction = 75.0 deg.
- Angular width (3 dB) = 247.8 deg.
- Side lobe level = -2.7 dB
Simulations w/out boom
Simulation Setup

- **CST Student Edition** – max 30,000 elements
- **Satellite (including mirror boxes):**
  - 1 mm thick Aluminum shell
    - CoreSat: 40 X 30 X 10 cm
    - MirrorSats: 10 X 10 X 37 cm
- **LVI ring:** Al cylinder, 1 cm thick, 12.4 cm OD, 6 cm height
- **LVI plate:** 1 cm thick plate
- **Antenna:** steel, tape measure profile
  - Variable length, angle relative to CoreSat
- **All components assumed to be in electrical contact**
UHF antenna, $\alpha = 0^\circ$ – Reflection Coefficient

- Antenna operating frequencies shift with changing configurations
- $L = 15$ cm a compromise between two configurations (close to expected $\frac{\lambda}{4}$)

![Graph showing S11 vs Frequency for Narrow and Wide configurations with different lengths L = 14.8 cm, L = 15 cm, and L = 15.2 cm. The graph includes UHF amateur band allocation.](image)
UHF antenna, narrow, $\alpha = 0^\circ$, $L = 15$ cm (437.5 MHz)

Frequency = 437.5
Main lobe magnitude = 2.16 dB
Main lobe direction = 135.0 deg.
Angular width (3 dB) = 244.2 deg.
Side lobe level = -3.3 dB

Frequency = 437.5
Main lobe magnitude = 0.603 dB
Main lobe direction = 356.0 deg.
Angular width (3 dB) = 343.6 deg.
UHF antenna, wide, $\alpha = 0^\circ$, $L = 15$ cm (437.5 MHz)

Far field realized gain Abs ($\Phi = 90$)

- Frequency = 437.5
- Main lobe magnitude = 3.2 dB
- Main lobe direction = 132.0 deg.
- Angular width (3 dB) = 135.6 deg.
- Side lobe level = -3.1 dB

Far field realized gain Abs ($\Theta = 90$)

- Frequency = 437.5
- Main lobe magnitude = 1.15 dB
- Main lobe direction = 119.0 deg.
- Angular width (3 dB) = 106.3 deg.
UHF antenna, $\alpha = 90^\circ$ – Reflection Coefficient

- Resonance shifted to higher frequencies but still good performance
- $L = 16$ cm compromise between configurations

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UHF antenna, narrow, $\alpha = 90^\circ$, $L = 16$ cm (437.5 MHz)

Frequency = 437.5
Main lobe magnitude = 2.21 dB
Main lobe direction = 12.0 deg.
Angular width (3 dB) = 158.1 deg.
Side lobe level = -2.1 dB

Frequency = 437.5
Main lobe magnitude = 2.59 dB
Main lobe direction = 359.0 deg.
Angular width (3 dB) = 89.1 deg.
Side lobe level = -2.6 dB

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UHF antenna, wide, $\alpha = 90^\circ$, $L = 16$ cm (437.5 MHz)

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VHF antenna, $\alpha = 0^\circ$ – Reflection Coefficient

- Antenna operating frequencies unaffected by changing configurations
- $L = 48 \text{ cm}$ for operation in amateur band (close to expected $\frac{\lambda}{4}$)
VHF antenna, narrow, $\alpha = 0^\circ$, $L = 48$ cm (145 MHz)

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VHF antenna, wide, $\alpha = 0^\circ$, $L = 48$ cm (145 MHz)

**Farfield Realized Gain Abs (Phi=90)**
- **Frequency** = 145
- **Main lobe magnitude** = 2.48 dB
- **Main lobe direction** = 84.0 deg.
- **Angular width (3 dB)** = 80.9 deg.

**Farfield Realized Gain Abs (Theta=90)**
- **Frequency** = 145
- **Main lobe magnitude** = 2.49 dB
- **Main lobe direction** = 76.0 deg.
Conclusions

• VHF operation acceptable with antenna at 0° in both configurations
  • S11 ~ -17 dB (VSWR ~ 1.35) at 48 cm length, 145 MHz
  • Expected monopole radiation pattern
  • Narrow: 2.34 dB; Wide: 2.48 dB

• UHF operation affected by LVI ring but still acceptable at 0° in both configurations
  • S11 ~ -20-30 dB (VSWR ~ 1.0 – 1.1) at 15 cm length, 437.5 MHz
  • Radiation pattern highly affected, non-isotropic, especially in wide configuration
    • 3dB beamwidths of 80 deg
space structures laboratory

AAReST CoreSat OBSW

Thibaud Talon
Antonio Pedivellano

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Outline

- Requirements
- Design / Architecture
  - Hardware abstraction layer
  - TCT handler / queue
  - Modules / Tasks
- State of the OBSW
  - Currently implemented code
  - Software to write
- Communications protocols
  - TCTM protocol
  - File Transfer protocol
- Example
- Future Work
- Questions
Requirements
<table>
<thead>
<tr>
<th>Needs</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communicate with the ground</td>
<td>Receiving data from ground should be interrupt-driven</td>
</tr>
<tr>
<td>Communication protocol for large data transmission</td>
<td>TCTM protocol must have limited overhead</td>
</tr>
<tr>
<td></td>
<td>File transfer protocol must allow transmission of files over multiple passes</td>
</tr>
<tr>
<td></td>
<td>Protocols must include error-detecting code</td>
</tr>
<tr>
<td></td>
<td>Must send beacon message with critical data</td>
</tr>
<tr>
<td>Obtain live telemetry for docking</td>
<td>Must be able to downlink live telemetry data during separation and docking:</td>
</tr>
<tr>
<td></td>
<td>a) ADCS parameters</td>
</tr>
<tr>
<td></td>
<td>b) MirrorSat and CoreSat critical health data</td>
</tr>
<tr>
<td>Control each subsystem from the on-board computer</td>
<td>Architecture must enable interfaces (I2C, UART, etc.) specified by each subsystem</td>
</tr>
<tr>
<td></td>
<td>Must provide interface code between ground messages and subsystems</td>
</tr>
<tr>
<td>Automatically control subsystems</td>
<td>Software must be real time</td>
</tr>
<tr>
<td></td>
<td>Software must be able to read scripts of commands</td>
</tr>
<tr>
<td>Ensure safety of spacecraft</td>
<td>Must monitor safety of satellite periodically</td>
</tr>
<tr>
<td></td>
<td>Must manage safe mode by only preserving critical systems</td>
</tr>
<tr>
<td></td>
<td>Must save critical data to non-volatile memory</td>
</tr>
<tr>
<td>Reprogram in-flight</td>
<td>Must include Bootloader to self program the OBC</td>
</tr>
</tbody>
</table>
Design / Architecture
Design / Architecture

• Microcontroller
  • EFM32 on CubeComputer (CubeSpace)
  • Interfaces available: I2C (x2), UART (x2), CAN, SPI

• Real Time Software
  • FreeRTOS
  • *Wide user base, flown on previous missions* (1), available on EFM32 programming software

• Software Architecture
  • Generously given by Surrey
  • Based on tasks for each subsystem and critical functions
  • Contains TCT handler / queue for message transfer between tasks
  • Interface with Hardware via a Hardware Abstraction Layer

Hardware Abstraction Layer

- List of functions for each interface
  - Transfer message over each interface

- Functions directly implemented in each task
  - No specific task for each interface
  - Except UART which is interrupt driven (used for Ground comms)

- Functions include Semaphore Mutex to prevent two tasks to access the same interface at the same time
TCT Handler / Queue

- Manages transfer of information between Tasks
- Messages are structures
  - Source ID
  - Reply ID
  - Return value
  - Destination ID
  - Message ID
  - Message type
  - Packet length
  - Packet (array)
TCT Handler / Queue

- Example: Beacon sending voltages and currents from EPS

<table>
<thead>
<tr>
<th>Source ID</th>
<th>UART TX (38)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reply ID</td>
<td></td>
</tr>
<tr>
<td>Return value</td>
<td></td>
</tr>
<tr>
<td>Destination ID</td>
<td>GomspaceEPS (41)</td>
</tr>
<tr>
<td>Message ID</td>
<td>81</td>
</tr>
<tr>
<td>Message type</td>
<td>request</td>
</tr>
<tr>
<td>Packet length</td>
<td>4 (default)</td>
</tr>
<tr>
<td>Packet (array)</td>
<td></td>
</tr>
</tbody>
</table>

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<td></td>
</tr>
<tr>
<td>Return value</td>
<td>Result (from I2C communication)</td>
</tr>
<tr>
<td>Destination ID</td>
<td>UART TX (38)</td>
</tr>
<tr>
<td>Message ID</td>
<td>81</td>
</tr>
<tr>
<td>Message type</td>
<td>ack</td>
</tr>
<tr>
<td>Packet length</td>
<td>21</td>
</tr>
<tr>
<td>Packet (array)</td>
<td>(Voltages and currents)</td>
</tr>
</tbody>
</table>
EPS task

Task infinite loop:

- Timer overflow?
  - No: Update Housekeeping values
  - Yes: Enter Safe Mode if voltage/power too low

- Incoming message?
  - No: Analyze incoming message
  - Yes: List of commands / messages
    - Read housekeeping values
    - Set outputs
    - Read/Set configuration
    - Reset
    - Etc.
Task infinite loop:

- Timer overflow?
  - No
  - Kick Internal WDT
  - Yes
  - Incoming message?
    - No
    - Yes
    - Analyze incoming message

List of commands / messages
- Check health (safe mode)
- Trigger safe mode, reset, etc.
- Set/Read unix time
- Test I2C, CAN lines
- Suspend/Resume tasks
- Change flight code (through bootloader)
- Manage watchdog timers
UART tasks

RX task infinite loop:

Received byte?  
No  
Yes  

Process byte

Full message?  
No  
Yes  

Send it to TCT Queue

Process byte:
- Look for Start of Message
- Look for End of Message
- Add byte to correct structure field
  - Destination ID
  - Message ID
  - Packet

TX task infinite loop:

Queued message?  
No  
Yes  

Format and send message to transceiver
Beacon task

Task infinite loop:

1. **Timer overflow?**
   - No
   - **Transmit Beacon**
   - **Incoming message?**
     - Yes
     - **Analyze incoming message**
     - **Transmit Beacon**
     - **Incoming message?**
       - Yes
       - **Analyze incoming message**
   - **Incoming message?**
     - No

List of Beacon values:
- **ADCS** (position and rates)
- **OBC** (safe mode, battery, power, reboot counts, AMRAD message)
- **EPS** (Voltages, currents, WDT info, temperatures)
- **Transceiver/Receiver** (Voltage, currents, temperatures, reception times, message counts, transfer times)
- **Payload** values

List of commands / messages
- Change beacon parameters
Automation task

Task infinite loop:

1. Timer overflow?
   - No
   - Yes
      - Execute Scripts
2. Incoming message?
   - No
   - Yes
      - Analyze incoming message

Scripts:
Automated list of commands
- Saved in SD card
- Each command has a start time, etc.
- Many scripts can be executed in parallel

List of commands / messages
- Schedule scripts
- Stop/Restart scripts
- Get status of scripts
- Write scripts
Mirror Box

Task infinite loop:

- Mirror Boxes are mainly controlled by the Telescope Camera
- The CoreSat only needs to interface with Box if Camera link is lost

List of commands / messages
- Read housekeeping values (register values)
- Set picomotor position
- Debug commands
- Etc.
State of OBSW
State of OBSW

- Hardware Abstraction Layer (from Surrey)
  - I2C
  - CAN
  - UART
  - Flash
  - GPIO
  - SD card
  - MCU
  - Time
  - Watchdog

- Fully implemented
State of OBSW

• Tasks (from Surrey)
  • File Transfer
  • OBC
  • UART comms
  • Beacon
  • Automation

• Fully implemented / minor updates

• Tasks (to implement)
  • EPS
  • ADCS
  • Transceiver/Receiver
  • Antenna deployment
  • MirrorSat
  • Docking/Undocking
  • Mirror boxes
  • Camera
  • Boom Deployement
  • Frangiblot
Communications protocols
TCTM Protocol (Jorge Llop)

- HDCL protocol
  - Less overhead on each message
  - Robust (flown before)

- TCTM Protocol

  - Example:
    - ADCS Telemetry, spacecraft velocity \((v_x, v_y, v_z)\).

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File Transfer Protocol

- **Saratoga protocol**
  - Fast, scalable, simple, and robust
  - Has heritage from Surrey missions
Example
EPS Telemetry request

- Format message on Ground

<table>
<thead>
<tr>
<th>2 Bytes</th>
<th>5 Bytes</th>
<th>3 Bytes</th>
<th>1 Byte</th>
<th>1 Byte</th>
<th>Variable Length</th>
<th>1 Byte</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decoder Flag</td>
<td>Callsign (AAReST)</td>
<td>Length of Message</td>
<td>Number of Increments</td>
<td>Group ID</td>
<td>Message ID</td>
<td>Payload Channels</td>
</tr>
</tbody>
</table>

- EPS Voltages and currents

- And send to spacecraft
The transceiver decodes the message.
Only the data part of the message is transmitted to the OBC
The reception of a byte creates an interrupt
The UART task reads and parses the data and creates a TCT message.

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The EPS task creates a TCT message

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The UART task reads the message and creates the downlink data.

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<td>(Voltages and currents)</td>
</tr>
</tbody>
</table>
The transceiver format the message to the ground
Open Issues

• **Actions during Docking operations?**
  - What data / telemetry is transferred
    - Telemetry to ground
    - Data from CoreSat to Surrey
  - Separate actions from Surrey and CoreSat

• **Automatically generated code?**
  - From Excel sheets
  - Creates code and documentation
  - How expensive is your Python Script?
Future Work

• Define lists of updates

• Progressively compile the code
  • Hardware Abstraction Layer
  • Tasks that don’t require hardware communication

• Write task code and test as hardware is available