Team #1 PI – SAT

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Mission Statement

We will design a low cost student-built satellite to observe the Earth’s atmosphere and land masses so that we can post pictures on Purdue’s website for public relations purposes.
Major Subsystems

- Payload
- Orbital Characteristics
- Communications
- Command and Data Handling
- Attitude and Control
- Structure
- Power
- Thermal
Payload – CMOS Camera

- Color CMOS Camera
  - Requires only 0.5 Watts and weighs 11 grams
  - Operating Temperature –10 °C to 55 °C
  - Picture has a 1km/pixel resolution with a picture size of 700km x 490km
  - Drawback - Not Space Qualified

Example of a CMOS Camera
Payload – Frame Grabber

Frame Grabber PCI Card

- Requires 5 Watts and weighs 150 grams
- Operating Temperature 0 °C to 50 °C
- Connected to the camera via a cable
- Not Space Qualified

Picture of a Frame Grabber
Orbital Characteristics

- Type: Sun Synchronous Orbit (Near Polar)
- Altitude: 800 km
- Inclination: 98.7°
- Right Ascension: 200°
- Mean Anomaly: 0°
- Eccentricity: 0
Footprint Sizing

- Length of Footprint $= \frac{D \sin \vartheta}{\sin \epsilon}$
- Width of Footprint $= D \sin \theta$
- Footprint size range from 2303 km to 1130 km from elevation range of 19 to 20 degrees
- Flat Earth Approximation
Trajectory Test Cases

Test Cases with variable RA

<table>
<thead>
<tr>
<th>Right Ascension</th>
<th>0 degrees</th>
<th>100 degrees</th>
<th>200 degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Orbit Data Transfer Duration</td>
<td>15 minutes 3 seconds</td>
<td>14 minutes</td>
<td>14 minutes 20 seconds</td>
</tr>
<tr>
<td>Second Orbit Data Transfer Duration</td>
<td>9 minutes</td>
<td>14 minutes 49 seconds</td>
<td>14 minutes 45 seconds</td>
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</table>

Test Cases with variable Mean Anomaly

<table>
<thead>
<tr>
<th>Mean Anomaly</th>
<th>0 degrees</th>
<th>100 degrees</th>
<th>200 degrees</th>
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</thead>
<tbody>
<tr>
<td>First Orbit Data Transfer Duration</td>
<td>14 minutes 20 seconds</td>
<td>9 minutes 59 seconds</td>
<td>15 minutes 11 seconds</td>
</tr>
<tr>
<td>Second Orbit Data Transfer Duration</td>
<td>14 minutes 45 seconds</td>
<td>15 minutes 11 seconds</td>
<td>14 minutes 27 seconds</td>
</tr>
</tbody>
</table>
Communication -Antenna-

- Helix omni antenna
- Gain=9dbi
- Coverage=30deg
- Height=15cm
- Diameter=9cm
- Weight=200gm
- C-band (4~8GHz)
### Communication –link budget–

#### Link Budgets for PI-SAT

<table>
<thead>
<tr>
<th>ITEM</th>
<th>SYMBOL</th>
<th>UNITS</th>
<th>UPLINK</th>
<th>DOWNLINK</th>
</tr>
</thead>
<tbody>
<tr>
<td>FREQUENCY</td>
<td>f</td>
<td>GHz</td>
<td>6.00</td>
<td>4.00</td>
</tr>
<tr>
<td>TRANSMIT POWER</td>
<td>P</td>
<td>W</td>
<td>50.00</td>
<td>4.20</td>
</tr>
<tr>
<td>BEAM WIDTH</td>
<td>θ</td>
<td>deg</td>
<td>~</td>
<td>30.00</td>
</tr>
<tr>
<td>GAIN OF ANTENNA</td>
<td>G</td>
<td>dbi</td>
<td>14.00</td>
<td>9.00</td>
</tr>
<tr>
<td>DATA SIZE</td>
<td>D</td>
<td>kbyte</td>
<td>50.00</td>
<td>800.00</td>
</tr>
<tr>
<td>DURATION OF CONTACT</td>
<td>t</td>
<td>minute</td>
<td>10.00</td>
<td>10.00</td>
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<tr>
<td>DATA RATE (HOUSE KEEPING)</td>
<td>Rh</td>
<td>bps</td>
<td>400.00</td>
<td>400.00</td>
</tr>
<tr>
<td>DATA RATE (PICTURE)</td>
<td>Rp</td>
<td>bps</td>
<td>~</td>
<td>15000.00</td>
</tr>
<tr>
<td>ANTENNA EFFICIENCY</td>
<td>η</td>
<td>%</td>
<td>65.00</td>
<td>60.00</td>
</tr>
<tr>
<td>max path length</td>
<td>km</td>
<td></td>
<td>3000.00</td>
<td>3000.00</td>
</tr>
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</table>

#### LOSSES

<table>
<thead>
<tr>
<th>LOSSES</th>
<th>SYMBOL</th>
<th>UNITS</th>
<th>UPLINK</th>
<th>DOWNLINK</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSMITTER LINE LOSS</td>
<td>Lₜ</td>
<td>db</td>
<td>-0.50</td>
<td>-1.00</td>
</tr>
<tr>
<td>SPACE LOSS</td>
<td>Lₛ</td>
<td>db</td>
<td>-195.30</td>
<td>-191.43</td>
</tr>
<tr>
<td>SYSTEM NOISE TEMP</td>
<td>k</td>
<td>K</td>
<td>650.00</td>
<td>135.00</td>
</tr>
<tr>
<td>polarization loss</td>
<td>Lₚ</td>
<td>db</td>
<td>-0.30</td>
<td>-0.30</td>
</tr>
</tbody>
</table>

#### OUTPUT

<table>
<thead>
<tr>
<th>OUTPUT</th>
<th>SYMBOL</th>
<th>UNITS</th>
<th>UPLINK</th>
<th>DOWNLINK</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIRP</td>
<td>~</td>
<td>dbw</td>
<td>30.49</td>
<td>14.23</td>
</tr>
<tr>
<td>Eb/No</td>
<td>~</td>
<td>db</td>
<td>18.34</td>
<td>2.04</td>
</tr>
<tr>
<td>C/No</td>
<td>~</td>
<td>db-HZ</td>
<td>44.36</td>
<td>43.80</td>
</tr>
<tr>
<td>BIT ERROR RATE</td>
<td>BER</td>
<td>~</td>
<td>1.00E-08</td>
<td>1.00E-04</td>
</tr>
</tbody>
</table>
Command And Data Handling

🌟 C&DH is Separated into 2 Sections

♦️ Hardware
  • Computer with memory

♦️ Software
  • Requirements have been set, exact package will be designed later.
Hardware

- Intel 386 CPU @ 25 MHz
- 8 MB of RAM
- 1 MB of ROM
- 8 MB SSD (Solid-State Disk)
- +5V±5% - 500 mA (active)/160 mA (sleep)
- Operating Range: 0° to 85°C
- Weight: .085 kg

Software

Tasks software will be required to do

- Put Satellite in Sleep/Active Modes
- Control Camera
  - Turn On/Off
  - Take Picture
- Extend Gravity-Gradient Boom
- Break up Data To Transmit (if needed)
To protect the Computer from radiation, it will be housed in an 1/8” thick aluminum box.
Attitude Determination & Control Subsystem

Requirements:
- Determine pointing to within 10°
- Maintain nadir pointing for camera

Solution
- Sun sensors and magnetometers for determination
- Passive gravity gradient stabilization with active magnetic control
- 2-axis stabilized, yaw axis is free
Attitude Determination

- **Sun Sensors**
  Model 0.5 sensors from Optical Energy Technologies
  - 2 sensors, 100° FOV each
  - 0.5° accuracy, 2-axis determination
  - Low Power (< 50 mW) Low Mass (<40g)

- **Magnetometer** Billingsly Magnetics model TFM100S
  - Low power (0.56W) Low mass (200g)
  - Course 3-axis attitude determination

- Earth Horizon sensors were considered, but were too heavy and consumed too much power. The level of accuracy given by these sensors was unnecessary.
Gravity Gradient stabilization

- Cheap and effective. A common approach for small nadir-pointing satellites.

Magnetic Control: 3 small axially-aligned Torqrods from Ithaco Inc.

- Low Power (0.54 W total), Low Mass (0.66 kg total)
- Dipole Moment of 1.1 Am²
  - Could be used to counter residual dipole internal to the satellite
  - Gives a torque of ~ 4.7x10⁻⁵Nm
  - Sufficient to counter disturbance torques from atmosphere (~2x 10⁻⁶ Nm) and solar pressure (~6x 10⁻⁶ Nm)

A momentum wheel was considered to help give 3-axis control, but such control is considered unnecessary.
Total Mass of Spacecraft = 41.4 Kg

- Mass goal of 50 Kg

Moments of Inertia – Kg/m²

- Iₓ = 16.3
- Iᵧ = 15.7
- I𝑧 = 0.93

- Favorable Moments of Inertia for Gravity Gradient

Center of Mass (boom extended)

- (0.26, 0.26, 0.43)
Structure

- Modeled in Ansys
  - Simplified Structure
    - Lumped Masses
    - Less Detail
  - Natural Frequencies (Hz)
    - 15.3, 17.7, 27.3, 33.7
    - Atlas II, IIA, IIAS – 15 (axial) / 10 (lateral)
    - Delta 6925/7925 – 35 (axial) / 10 (lateral)
Structure

Material Selection

❖ Beams
  • Aluminum 6061
  • 2.5 x 2.5 cm Hollow Square Tubes, thickness of 0.3 cm

❖ Stringers
  • Aluminum 6061
  • 2.5 x 2.5 cm L-Angle, thickness of 0.16 cm

❖ Sheets
  • Aluminum 6061 or possibly Composite material
  • 0.5 x 0.5 m, thickness of 0.15 cm
Power

- Four body mounted GaAs cell panels.
  - Area of 0.305 m² each.
  - 36W each; Peak 50 W.
- 8 Li-Ion batteries cells.
- Power system also consists of a battery charge monitor (BCM) and power conditioner.
- A max power of 30 watts to the subsystems will be provided at 26 volts.
Power Layout

Solar Panel

Battery Charge Regulator

Power Distribution Module

Battery
26V
3.5 Ah

To Satellite Subsystems
## Power Budget

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Full Power [Watts]</th>
<th>Data Transfer Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communications</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Magnetic Torquer #1</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>Magnetic Torquer #2</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>Magnetic Torquer #3</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>Sun Sensor #1</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Sun Sensor #2</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Magnetometer</td>
<td>0.56</td>
<td>0.56</td>
</tr>
<tr>
<td>Payload</td>
<td>5.5</td>
<td>0</td>
</tr>
<tr>
<td>CD&amp;H</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>23.7</strong></td>
<td><strong>13.2</strong></td>
</tr>
<tr>
<td><strong>25% Margin</strong></td>
<td><strong>5.925</strong></td>
<td><strong>3.3</strong></td>
</tr>
<tr>
<td><strong>Total Power needed</strong></td>
<td><strong>29.625</strong></td>
<td><strong>16.5</strong></td>
</tr>
</tbody>
</table>

E=Exact
A=Approximate
Power Distribution in Transfer Mode

- CD&H: 31%
- Communications: 43%
- Margin: 20%
- Sun Sensor #2: 0%
- Sun Sensor #1: 0%
- Magnetic Torquer #3: 1%
- Magnetic Torquer #2: 1%
- Magnetic Torquer #1: 1%
- Magnetometer: 3%
Battery Characteristics

Charge and Discharge

Temperature Range
Thermal

Temperature Estimate

- External thermal range of 315K to 205 K
- Using multilayer insulation (MLI) blankets we isolate the internal components.
Operating Temperature Range [°C]

- Payload: 0 to +50
- CD&H and Comm: -10 to +20
- Power: 0 to +30
- Sensors: -30 to +50
- Structures: -40 to +50