High Performance Optical Imaging Payloads for Smallsat Missions

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Outline

• Camera & Spacecraft Dev’t Program Overview
• Optical Camera Design
• Camera Hardware Testing
• Payload Controller, Processor & Memory Unit (PCPMU)
• Camera System Performance
• Hi-Res Optical Spacecraft Design
• Summary
Development Program Overview

• Two classes of Hi-Res Camera in development
  – RALCam-4: 1.0 m GSD @ 600 km altitude
  – RALCam-5: 0.5 m GSD @ 500 km altitude

• Camera’s designed together to share same technology
  – Telescope optics & structure identical  BUT  RALCam-5 is scaled up in size to increase aperture
  – Focal Plane & Electronics Assembly (FPEA) is same for both

• PCPMU is MDA’s re-configurable payload electronics
  – performs all payload control & data handling for future MDA missions
  – Both classes of optical camera, radar missions & Comms missions

• Developed MDA’s next-generation Hi-Res mission offering
  – Leveraged elements of the RapidEye spacecraft design
Payload Architecture

- **OPTICAL CAMERA**
  - Telescope Optics & Structure
  - Focal Plane & Electronics Assembly (FPEA)

- **Payload Controller, Processor & Memory Unit (PCPMU)**
  - Camera Command
  - Image Data

- **X-Band Tx 1-2**
  - I,Q,CLK
  - Gimbal Control

- **Antenna Gimbals 1-2**
  - ANTENNA

- **Spacecraft Bus**
  - Heater Power
  - FPEA Power
  - ON-OFF
  - PPS Synch
  - PCPMU Power
  - CAN

**MDA**
RALCam-4 Optical Camera

Key Parameters

- Mass: 76 kg
- Power: 60 W
- Length: 1.17 m
- Height: 0.75 m
- Width: 0.83 m
- Focal Length: 6000 mm
- Aperture: 480 mm

- Near-zero CTE materials used (CFRP & Zerodur)
RALCam-5 Optical Camera

The following are changes from RALCam-4:
- scaled up in size to increase aperture
- increased detectors in focal plane
- “wrap around” camera frame

Key Parameters
- Mass: 220 kg
- Power: 120 W
- Length: 1.95 m
- Height: 1.25 m
- Width: 1.38 m
- Focal Length: 10,000 mm
- Aperture: 800 mm
- Same materials as RALCam-4
RALCam 4 & 5 Focal Plane

5 spectral bands:

- **PAN**: 450 – 700 nm
- **Blue**: 450 – 520 nm
- **Green**: 520 – 600 nm
- **Red**: 630 – 690 nm
- **NIR**: 760 – 900 nm

**PAN Sensor**
- Pixel size: 10µm
- Number of pixels: 20,580 (RALCam-4), 32,868 (RALCam-5)
- Number of TDI stages: 96

**MS Sensor**
- Pixel size: 40µm
- Number of pixels: 4 x 5,145 (RALCam-4), 4 x 8,217 (RALCam-5)
- Number of TDI stages: 16

Not used for RALCam-4
Optical Camera Key Features

• Active On-Orbit Optics (AO$^3$) System
  – Telescope optics re-aligned in space using a proprietary approach
  – Removes need to maintain very high optical component stability from Lab to on-orbit - a significant cost driver
  – Maintains high image quality

• FPEA
  – Custom CCD’s (Pan and MS) developed with e2v (UK) from ground up together with Front End Electronics (RAL)
  – Leverage heritage processes & technology for ultra-high data quality
  – Designed to allow for low recurring costs – optimized to reduce price point

• Telescope
  – CFRP telescope structure & zerodur mirrors – provide near-zero CTE and remain low cost

• Camera Structural and Thermal Isolation from Bus
  – Elastomeric isolators used (with launch locks) for jitter suppression
  – Also provide thermal & structural isolation (e.g., bus distortion or non-flatness a non-issue)
Optical Camera Dev’t Status

• The camera design is based significantly on the technology developed and proven on the RALcam-1 camera
  – in-orbit on the Topsat Mission since 2005

• The camera design is well advanced and hardware procurement is in process (long lead items)
  – Key design elements based on proven well understood technologies & processes (e.g., AO³ actuators, CCD detector)
  – Key Suppliers identified
  – Mirror procurement in process
  – Focal plane layout and CCD designs are defined
  – Key components identified, risk-reduction test program in process

• Significant risk reduction work has already been undertaken
  – Structural engineering model built and tested to confirm structural design and optical element stability under loads (a key risk)
  – Detailed optical design and analysis performed that assesses tolerancing and other manufacturing related elements
Testing Status

Structural qualification model of telescope underwent environmental test campaign
- Vibration
- Thermal-Vacuum

Key Test Results:
1. Telescope survived the typical launch environments.
2. Natural frequency meets requirements.
3. Optical alignment stability during vibration is well within the correction capability using the AO$^3$ system (with ample margin).
4. CTE of the telescope tube was measured and found to be $0.2 \times 10^{-6} \, ^{\circ}\text{C}$.
5. Qualified primary mirror mounting technique to the bulkhead panel (used dummy optics).
PCPMU

- Provides Instrument Control
- Drive electronics
  - X-band antenna gimbals
  - Camera AO³ alignment system
- JPEG2000 compression (real-time)
- Large On-board data storage capacity
  - Non-volatile memory (Flash)
  - 0.5 to 4 Tbits at EOL
- Data formatting (e.g., CCSDS, RS encoding)
- Data Encryption (triple DES or AES)
- Instrument high speed data interface
  - up to 8 Gbps
- Interface to X-Band Tx (up to 800 Mbps)
- Power conditioning
- Fully redundant architecture
  - RALCam-4: 12 boards (8 powered)
  - RALCam-5: 16 boards (11 powered)

RALCam-4:
- Mass = 21 kg
- Power = 58 W (imaging)
  - 82 W (Imaging & DL)
  - 0 W (data retention)

RALCam-5:
- Mass = 27 kg
- Power = 87 W (imaging)
  - 95 W (Imaging & DL)
  - 0 W (data retention)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Detail</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GSD</strong></td>
<td>Pan band (@ 600 km)</td>
<td>1.0 m</td>
</tr>
<tr>
<td></td>
<td>MS bands</td>
<td>4.0 m</td>
</tr>
<tr>
<td><strong>Swath Width</strong></td>
<td>Pan &amp; MS bands (@ 600 km)</td>
<td>20.6 km</td>
</tr>
<tr>
<td><strong>MTF</strong></td>
<td>Pan band - across track</td>
<td>&gt; 16.1%</td>
</tr>
<tr>
<td></td>
<td>Pan band - along track</td>
<td>&gt; 10.8%</td>
</tr>
<tr>
<td><strong>SNR</strong></td>
<td>Pan band</td>
<td>&gt; 146</td>
</tr>
<tr>
<td></td>
<td>sun angle = 67.3 deg, TDI = 24</td>
<td></td>
</tr>
<tr>
<td><strong>TDI levels</strong></td>
<td>Pan / MS bands</td>
<td>96 / 16</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>Pan &amp; MS bands</td>
<td>12 bits</td>
</tr>
</tbody>
</table>
### RALCam-5 Performance Spec

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>GSD</td>
<td>Pan band (@ 600 km)</td>
<td>0.5 m</td>
</tr>
<tr>
<td></td>
<td>MS bands</td>
<td>2.0 m</td>
</tr>
<tr>
<td>Swath Width</td>
<td>Pan &amp; MS bands (@ 600 km)</td>
<td>16.4 km</td>
</tr>
<tr>
<td>MTF</td>
<td>Pan band - across track</td>
<td>&gt;16.1%</td>
</tr>
<tr>
<td></td>
<td>Pan band - along track</td>
<td>&gt;10.8%</td>
</tr>
<tr>
<td>SNR</td>
<td>Pan band</td>
<td>&gt; 98</td>
</tr>
<tr>
<td></td>
<td>sun angle = 80.1 deg, TDI = 96</td>
<td></td>
</tr>
<tr>
<td>TDI levels</td>
<td>Pan / MS bands</td>
<td>96 / 16</td>
</tr>
<tr>
<td>Resolution</td>
<td>Pan &amp; MS bands</td>
<td>12 bits</td>
</tr>
</tbody>
</table>
0.8 m / 1.0 m Class Spacecraft
Spacecraft Configuration

- Camera Support Frame
- Bus Avionics
- X-Band Tx
- Propulsion Module
Spacecraft Configuration

Spacecraft Mass: 366 kg
Power generation: 132 W (Orbit average)
Propulsion Module

Cold Gas Prop System Baseline
Delta V = 35 m/s
Altitude = 600 km (gives 1 m GSD)

Hydrazine Prop System Option
Delta V = 165 m/s
Altitude = 480 km (gives 0.8 m GSD)
Low Cost Launch Options

- Falcon 1E launch vehicle
- DNEPR launch vehicle
- Soyuz launch vehicle
0.5 m Class Spacecraft
Low Cost Launch Options

Minotaur IV launch vehicle

Falcon-9 launch vehicle
Summary

• MDA’s Hi-Res optical cameras and spacecraft
  – designed to provide very high image quality at highly competitive price points
  – S/C price point enables launching small constellations to provide unprecedented coverage and performance
  – High Reliability & Lifetime (> 7 years)

• Key Price Point Enablers
  – AO³ system
  – Integrated Focal Plane & FEE in the FPEA
  – PCPMU
  – Proven Processes for use of commercial EEE parts
  – Highly compact S/C design requiring low power
    • deployed solar panels not required, high agility, low cost launch options