Microsized Microwave Atmospheric Satellite (MicroMAS)

Overview

• About MicroMAS
• Movies
• Key design features
• Integration and test
  – Stack buildup
  – ADCS
  – Mass mockup
• Path forward
• Long term goal: constellation
Hurricanes, Tropical Storms, and Typhoons

• Super Typhoon Pongsona (Dec 8, 2002)
  – MODIS image (Terra)
  – Want the core and water vapor with altitude
  – Microwave radiometers do this
“Looking them in the eye”

- Atmospheric Infrared Sounder (AIRS) with Advanced Microwave Sounding Unit (AMSU) on Aqua (Sun-synch)
Cloud Penetration

- MicroMAS 118 GHz, 9 channels
• Channels sample different altitudes
Why put radiometers on CubeSats?

• Currently in sun-synch orbits
  - Twice daily revisits
  - Better temporal coverage with LEO CubeSats (90 min)
  - Lower altitude, better signal + resolution

• Cost
  – $1B vs 1M

• Replaceable

• Distribute channels

AIRS/AMSU (NASA Aqua) Mosaic of Ascending Orbits on Sep 6, 2002
MicroMAS modeled performance

- Super Typhoon Pongsona (Dec 8, 2002)
MicroMAS

- http://www.youtube.com/watch?v=hY3YMs5Z1b0&feature=youtu.be
Objectives

- Focus on hurricanes + severe weather
- 500-km orbit altitude
- 25-km pixel diameter at nadir (cross-track scan out to ±50°)
- 1 K absolute accuracy
  - 0.3 K sensitivity
- Geolocation error threshold
  52 arcmin
  - 30% of 25 km pixel diameter at altitude of 500 km
- 20 kbps (avg) downlink
- 12 W (avg) power
- One year mission lifetime
- 2014 launch by NASA ELaNa

3U CubeSat
MicroMAS Nanosatellite
• 3U CubeSat
• 1U Payload + 2U Bus connected via custom scanner assembly
• 4, 2U double-sided deployed and body-mounted solar panels
• Deployed measuring tape antenna
• MAI 400 ADCS Module
Design Overview

Bus

Solar Panel Interface Plate
MAI-400 ADCS Unit
Avionics Stack

Payload
Scanner Assembly Motor
Systems Integration

- **Bottom Interface Plate**
- **MAI-400**
- **Bus Stack**
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- **Chassis**
- **Scanner Assembly**
- **Antenna Assembly**
- **Solar Panels**
Systems Integration

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  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels (stowed)
Getting it to spin

- Brushless dc zero cogging motor, controller
- Encoder
Scanner Assembly Movie
Radiation Testing

- Cobalt-60 TID testing of critical components.
- Mission dose: **1.2 krad** (SPENVIS)
- All devices passed functional tests after 8 krad dose.
- Test limitations:
  - No SEL or SEU testing
  - Low sample sizes
- Upcoming test: TCXO, another PIC

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>8 krad</th>
<th>24 krad</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPF2700</td>
<td>Current limit switch</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>MAX3221-EP</td>
<td>RS232 transceiver</td>
<td>PASS</td>
<td>FAIL</td>
</tr>
<tr>
<td>PIC24FJ256GA110</td>
<td>PIC24F microcontroller</td>
<td>PASS</td>
<td>FAIL</td>
</tr>
<tr>
<td>PIC24EP512GU810</td>
<td>PIC24E microcontroller (alt. CPU)</td>
<td>PASS</td>
<td>FAIL</td>
</tr>
<tr>
<td>SE02SAMHL-C1000-D</td>
<td>Industrial SD card (Delkin)</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>LT6003 + photodiode</td>
<td>Op-amp (sun sensor circuit)</td>
<td>PASS</td>
<td>PASS</td>
</tr>
</tbody>
</table>
Radiation Testing

TID Tolerance of Popular CubeSat Components

R. Kingsbury, F. Schmidt, K. Cahoy and D. Sklarl
Space Systems Lab
Massachusetts Institute of Technology
Cambr

Abstract—In this paper we report total dose test results for COTS components commonly used on CubeSats. We investigate the TID tolerance of popular microcontrollers (PIC24) as well as SD memory cards.

I. INTRODUCTION

In this paper we present the results from total ionizing dose (TID) testing that was completed for components in the MicroMAS satellite. MicroMAS, the Micro-sized Cislunar Atmospheric Satellite, is a 3U CubeSat under development by the Space Systems Lab at MIT and Linx Laboratory [1]. This three-axis stabilized CubeSat will have a state of the art passive microwave radiometer. In order to test the TID tolerance of the components, we used a test jig similar to the one shown in Fig. 1. The test jig includes a power supply for the components and dosimetry tablets for measuring the TID exposure levels.

TABLE I

<table>
<thead>
<tr>
<th>DUT</th>
<th>Dose</th>
<th>$I_{thp}$ (mA)</th>
<th>$V_{ON}$ (mV)</th>
<th>$V_{OFF}$ (mV)</th>
<th>$I_{Q}$ ($\mu$A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>0 krad</td>
<td>0.447</td>
<td>162</td>
<td>2.1</td>
<td>92</td>
</tr>
<tr>
<td>#1</td>
<td>8 krad</td>
<td>0.447</td>
<td>90</td>
<td>2.1</td>
<td>89</td>
</tr>
<tr>
<td>#2</td>
<td>0 krad</td>
<td>0.509</td>
<td>156</td>
<td>1.6</td>
<td>92</td>
</tr>
<tr>
<td>#2</td>
<td>24 krad</td>
<td>0.505</td>
<td>77.2</td>
<td>1.6</td>
<td>105</td>
</tr>
</tbody>
</table>

TABLE II

<table>
<thead>
<tr>
<th>DUT</th>
<th>Dose</th>
<th>$I_S$ (mA)</th>
<th>$V_{open}$ (V)</th>
<th>$V_{load}$ (V)</th>
<th>$t_{HIL}$ (ns)</th>
<th>$t_{HL}$ (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>0 krad</td>
<td>0.36</td>
<td>L: -5.579</td>
<td>H: +5.578</td>
<td>560</td>
<td>400</td>
</tr>
<tr>
<td>#1</td>
<td>8 krad</td>
<td>0.43</td>
<td>L: -5.420</td>
<td>H: +5.484</td>
<td>620</td>
<td>430</td>
</tr>
<tr>
<td>#2</td>
<td>0 krad</td>
<td>0.33</td>
<td>L: -5.516</td>
<td>H: +5.517</td>
<td>580</td>
<td>440</td>
</tr>
<tr>
<td>#2</td>
<td>24 krad</td>
<td>0.70</td>
<td>L: +0.140</td>
<td>H: +0.004</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

B. MAX3221-EP RS232 Interface

The MAX3221-EP is a TIA/EIA-232 compliant line transceiver that can be powered from a 3.3V power supply. This device contains a charge pump circuit that is used to produce the necessary RS-232 signaling levels. The following device parameters were selected for TID characterization:

- No-load supply current ($I_S$)
- Driver output voltages without load ($V_{load}$)

- Want to test PIC24FJ256GB210 (new option 98 vs. 16 kB RAM) and TCXO (FOX924B-16.000)
## Integration & Test I

<table>
<thead>
<tr>
<th>Elmo Hornet motor controller</th>
<th>Perkin Elmer thermopiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Test in vacuum over varying temps</td>
<td>- Test in vacuum over varying temps</td>
</tr>
<tr>
<td>- Test on Elmo development board</td>
<td>- Test varying FOVs of a hot plate</td>
</tr>
<tr>
<td>- Test with Pittman motor connections</td>
<td>- Characterize sensor data</td>
</tr>
<tr>
<td>- Read telemetry</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MicroE Encoder (disk + sensor)</th>
<th>Clyde Space batteries</th>
<th>RTD thermal sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Test in thermal oven over varying temps</td>
<td>- Test internal thermostatically controlled heaters</td>
<td>- Test functionality and range in vacuum</td>
</tr>
<tr>
<td>- Characterize failure modes and criteria</td>
<td>- Characterize sensor data</td>
<td>- Characterize sensor data</td>
</tr>
<tr>
<td>- Characterize sensor data</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Integration & Test II

Scanner assembly

- Test encoder + sensor functionality in vacuum
- Test CTE mismatches between bearing + shaft
- Test conductance and radiance to payload
- Test workmanship and alignment in vacuum over varying temperatures

Top interface board

- Test connections in vacuum over varying temperatures
- Test with motor controller, gyroscope, and magnetometer
- Characterize data output

Bottom interface board

- Test connections in vacuum over varying temperatures
- Characterize data output

CAD image: E. Peters

Design image: R. Kingsbury

Image from MicroE

Design image: R. Kingsbury

4/28/2013
Detailed Mass Mockup
ADCS Test Rig
MIT Ground Stations

• UHF/VHF Station
  – MIT Radio Society is assembling a “standard” UHF/VHF station
  – Two az-el steerable yagi antennas
  – Approximately 100W of
  – Undergoing final integration this spring

• S-Band Station
  – A much bigger project...
MIT Green Building Dish

• 5.5 meter (18 ft) dish
• Originally installed for weather radar research
• Pedestal is WW2 surplus SCR-584
• Modified in 1960s
  – Increased dish size
  – Added radome
  – Waveguide feed
Path forward

• Waiting to get manifest
  – Ready for early 2014
• Flight motor integration and test
• MAI-400 delivery, ADCS testing
  – Helmholtz cage, air bearing testing
• Additional radiation tests
• Software: linear algebra on PIC24
• Solar panel assembly delivery, integration
• Antenna fabrication, integration, tuning, characterization
• Ground station simulator, testing → MIT ground stations

RAX-2 and M-Cubed launch on Delta II
28 Oct 2011
Marinan, Nicholas and Cahoy, “Ad hoc CubeSat Constellations.” IEEE Aerospace 2013

One satellite per plane

<table>
<thead>
<tr>
<th>Case</th>
<th>Revisit Time (Avg, hrs)</th>
<th>Response Time (Avg, hrs)</th>
<th>Hours to 100% Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walker</td>
<td>8</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Ad Hoc 1</td>
<td>12</td>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>Ad Hoc 2</td>
<td>6</td>
<td>13</td>
<td>12</td>
</tr>
</tbody>
</table>

Six satellites per plane

<table>
<thead>
<tr>
<th>Case</th>
<th>Revisit Time (Avg, hrs)</th>
<th>Response Time (Avg, hrs)</th>
<th>Hours to 100% Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walker</td>
<td>0.8</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Ad Hoc 1</td>
<td>1.0</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>Ad Hoc 2</td>
<td>0.7</td>
<td>9</td>
<td>8</td>
</tr>
</tbody>
</table>
Backup
<table>
<thead>
<tr>
<th></th>
<th>Operational Overview</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Mission Planning/Pre-Launch Integration</td>
</tr>
<tr>
<td>1</td>
<td>Launch as secondary payload</td>
</tr>
<tr>
<td>2</td>
<td>On-orbit deployment and initialization</td>
</tr>
<tr>
<td>3,4</td>
<td>Mission Ops - 6 months nominal</td>
</tr>
<tr>
<td>5</td>
<td>Fault Recovery/Limited Ops</td>
</tr>
<tr>
<td>6</td>
<td>Mission Termination</td>
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</table>
"Flat Sat" Engineering Model

ADCS Testbed Platform:
Precision design with mass mock-ups, designed for repeatable tests of ADCS modes (currently in design phase)
Design Overview

CubeSat Development
Air Bearing/Helmholtz Cage

- Air bearing encased in Helmholtz coil
- Plan to add hot plates for EHS stimulus
Thermal Vacuum Chamber

• SSL Chamber
  – Plan to use as clean chamber for integrated system testing

• Kavli Small and Large Chambers
  – Component-level testing, bake-outs

• SSL ‘Desktop’ Chamber
  – Component-level testing, bake-outs
• Board-level testing and assembly
  – Pumpkin CubeSat development board
Clean Room

- ISO Class 8
- ESD mats and straps
- Integrated Thermal-Vacuum chamber (TBD)
Testing Facilities

Kavli Small Chamber
- Size: 8.25” I.D. x 15” L
- Pressure: < 1E-05 torr
- DAQ: Currently borrowing Agilent 34970A and PC from AA Gelb Lab

Status: READY

Kavli Large Chamber
- Size: 20” I.D. x 26” L
- Pressure: < 1E-05 torr
- DAQ: Integrated with Agilent 34970A and remote desktop PC

Status: READY

SSL Clean Chamber
- Size: 2’ x 2’ x 2’
- Pressure: < 1E-05 torr
- DAQ: TBD

Work Needed:
- Move into final location
- Supply with 220V power
- Replace O-ring, few parts
- Procure DAQ and PC

Status: NOT READY

02/26 – 05/19/13
Finite Element Modeling

• Created finite element models of chassis, circuit board stack, and integrated assembly

• Lowest system mode: 189 Hz
  – Well above 70 Hz requirement
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