A Highly Modular Scientific Nanosatellite

Taylor University
University of Illinois
University Nanosat III

August 9th-12th, 2004
Logan, Utah
SSC04-VIII-6
Thunderstorm Effects in Space Technology

Test is dedicated to:

- Student education and training in space science and technology.
- The execution of innovative design strategies for real-world nanosatellite mission objectives.
- Cutting-edge space science and research.

Science

- Source and propagation of acoustic gravity waves.
- Lightning induced electron precipitation and coupling into radiation belt.
- Thunderstorm coupling to the ionosphere, heating, quasi DC electric fields, and global electric circuit fields.

Technology

- Multiple complementary instrumentation in a small package.
- Modular mechanical and electrical busses.
- Onboard CubeSat launch platform.
- Two-stage passive radiator.
- 900 MHz spread spectrum communication.
- 3-axis reaction-wheel attitude control.
Experiment 1 & 2: Imager & Hertzberg Photometer

Imager – Study dynamic effects in Ionosphere and neutral atmosphere
- Ionized Oxygen Airglow
- Wavelengths >200km
- 1% to 50% intensity variation

Oxygen airglow perturbations carried by wind

400km Orbit

Hertzberg Photometer – Study dynamic drivers of upper Mesosphere
- Oxygen Airglow
- Wavelengths 15 to >2500km
- ~0.5% to 6% intensity variation

400km

100km

95km Altitude

Thunderstorm convection

Mountains
Experiment 1 & 2: Imager & Hertzberg Photometer

CCD Imager
- **Purpose:**
  Provide information for study of AGWs, TIDs, and lightning by sensing emissions in the 630 nm region.
- **Modes of Operation**
  - Main Mode: Keogram
  - Full Frame
- **Hardware Specifications**
  - S/N > 50 w/ 8 deg FOV
  - Camera: 512 pixel array
  - Resolution of 2 to 5 km
  - PMT: R7400U-20, Gain of $5 \times 10^5$
  - Background Imager

Hertzberg Photometer
- **Purpose:**
  Provide information for study of AGWs, TIDs, and lightning by measuring the intensity of the $O_2$ Hertzberg band.
- **Hardware Specifications**
  - 200 w/ 0.9 deg FOV
  - Photodiode protection circuit
  - Low voltage protection
  - Background photometer
Experiments 3, 4, & 5: Plasma Probe, Electric Field Probe, & VLF Receiver

**Electric Field Probe**
- Measures local DC electric field
- Hardware/Operational Specifications
  - Probes extend in the vertical and horizontal directions.
  - AC modulations monitored

**Langmuir Plasma Probe**
- Measures local electron density.
- Hardware/Operational Specifications
  - Extends 20 cm from satellite body.
  - Conducting sphere w/ programmable voltages attracts oppositely charged particles.

**VLF Receiver**
- Measure VLF radio energy
- Hardware/Operational Specifications
  - Connected to log electrometer and amplifier.
  - 500 Hz – 3 KHz and 8 KHz – 33 KHz frequency ranges are attained using two switch-capacitor band-pass filters.
  - Capacitor and bleed resistor used for data digitization.
Experiment 6 & 7: Particle Spectrometer & Transient Photometer

Particle Spectrometer

• Measures quasitrapped electron and ion particle flux.
• Hardware/Operational Specifications
  • Primary and secondary radiators mounted on dark side of orbit to maintain –60 deg. C temperature.
  • 10 KeV to 1 MeV electron energy range.
  • 80 KeV to 2 MeV ion energy range.
  • Permanent magnets sweep out low mass particles.
  • 1000 channel digital pulse processor.

Transient Photometer

• Captures light emissions from lightning and aurora
• Hardware/Operational Specifications
  • Barr filter locks onto peak nitrogen band frequency.
  • Hamamatsu PMT w/ built in power supply.
  • Programmable gain and resolution.
Freewave Radios, Cubesat Launch Platform, & Passive 2-Stage Radiator

Freewave 900 MHz Spread Spectrum Radio
- High data rate transmission.
- Hardware/Operational Specifications
  - -106 dBm sensitivity.
  - 56 Kbps throughput with Doppler shift correction.
  - Grand master-slave operation allows for dual transmission and system redundancy.

CubeSat Launch Platform
- Allows for secondary CubeSat payload and launch capabilities.

2-Stage Passive Radiator
- Cools solid state particle detector to –60 deg C.
- Hardware/Operational Specifications
  - Isolated by stainless steel connectors, reflective tape, and thermal blankets.
  - Fiberglass standoffs isolate primary radiator from secondary radiator.
3-Axis Attitude Determination and Control

• Purpose
  Maintain three-axis stability for limb and nadir viewing.

• Hardware/Operational Specifications
  • Three-axis Honeywell magnetometer
  • Pitch and Roll horizon sensors.
  • Four-wheel 88 mNm reaction wheel assembly.
  • 6-torque coil configuration for momentum dumping.

• Algorithm and Flight Software
  • State-space controller design.
  • Automatic gain determination.
  • Flight and simulation software written with Simulink
  • Automatic code generation with Real-Time Workshop allows for platform independence.
Structures and Mechanisms

- **Bus:**
  - 32cm x 32cm x 47cm
  - Constructed of Al 6061
  - Fasteners: Stainless steel, Fiberglass
  - Satellite Weight < 30 Kg

- **Structural Components**
  - Exoskeleton: Four primary load bearing walls with interconnecting ribs
  - Bottom plate of Exoskeleton designed for Lightband® attachment with bolt back-out protection
  - Top Plate designed for addition of secondary Lightband® unit or a four unit CubeSat P-Pod Deployer
  - Shear plane added to structure to increase the satellite’s fundamental frequencies
  - Interior cube matrix for stress relief and load translation
• Modular Subsystem Design
  – Standard 4”x4”x4”
  – Internal connecting of subsystem boxes by stainless steel or Teflon bolts for thermal or electrical isolation of subsystems
  – Low-cost, able to be manufactured in-house. Cubes fabricated from 4”x4” extruded aluminum
  – Standardization for future satellite buses

• Standardized mounting and fasteners
  – All subsystem modules mount to external exoskeleton walls
  – Standard “Scoop-Proof” electrical connector interface: D-sub 9,15, or 25
  – PCB stack with internal Dsubs
Structures and Mechanisms

• Release Mechanism
  – Pin puller design utilizes MicroMotor DC motor with 1024:1 planetary gear head and encoder
  – Built in bearing for easy shaft rotation
• Electric Field / VHF Antenna Booms
  – Aluminum hinge with motor built into hinge assembly providing controlled deployment
  – Encoder provides precise location of deployment
  – Shaft Material: hollow Garolite meets probes electrical and mechanical requirements
  – Length per boom: 46 cm
  – Magnetometer boom: isolation of Honeywell Magnetometer
• 70cm/2m Antenna
  – Antenex ¼ wave whip antenna
  – Feed point below Reflector Shield for optimum earth propagation
• Thermal Shield
  – Aluminum wall structure
  – In house hinge assembly utilizing deployable motor assembly
  – Shields the earth’s albedo from the thermal radiator
  – Plasma probe boom: housing fastened to exterior of shield
Wire Harness

- **Motherboard**
  - Central routing board minimizes external subsystem wiring
  - LED's placed onboard for subsystem diagnostics
  - Subsystem microcontroller programming connectors placed on board
  - Six diagnostics pins defined by subsystem teams for debugging after assembly
  - Provides interface for redundant beacon inputs

- **Harness**
  - Harness from subsystems directly to Motherboard
  - All cables utilize D-Sub connectors providing a high degree of reliability
  - Cables able to be made in-house
C&DH Architecture

• Purpose
  – Acquire and store data from the instruments and command each instrument
  – Standardized software and multiple applications

• Hardware
  – Two Arcom Vipers, Intel PXA255 400 MHz processor (Runs embedded Linux)
  – 512 Mbytes Compact Flash
  – Five MicroChip 18FXXX Microcontroller's

• Interface Board
  – Customized interface board standardizes common subsystem functions
  – Acts as a smart A/D (Microcontroller)
  – Interface board has the capabilities of up to 8 Analog, 25 I/O, subsystem current monitoring and shut off, and up to 512 Kbytes of SRAM

• TEST supports multiple data busses
  – RS485 – Primary Data Transfer Bus
  – RS232 – Communication with COTS components
  – I²C – Beacon/Back up Data bus
  – Dallas 1-Wire – Power system relay/ADC
  – Scadata 1-Wire – Beacon and Educational cube bus
Educational/Additional Cubes

- Beacon Module
  - Collects data from multiple number of additional cubes
  - Provides a buffer from the primary (tested) C&DH
  - Connected to Beacon transceiver through RS232 for transmission to earth

- Educational/Additional Cubes
  - Common interface board able to be utilized or customized boards
  - Communicates with the Beacon Module through Scadata 1 wire bus
  - Can be “plug and play”
  - Confined cube allows for educational institution, or additional scientific instrument
  - Standardized connector/data format allows complete development externally with little communication
Power Subsystem

Specifications
• Minimal Single Point Failures:
  – Redundant battery packs
  – Resettable fuses to prevent latch-up
  – Redundant 5V regulators
• Provide –5V, 5V, 8V, 12V, and an unregulated power bus, capable of 3A each
• DC-DC Conversion Efficiencies > 80%
• Hardware Peak Power Tracker
• Industry proven Dsub connectors for all internal and External connections
• Centralized buck regulators reduces risk of noise injection into sensitive science instruments
• Star ground topology to prevent ground loops, along with an analog ground for sensitive instruments
### Summary of Modularity: Disruptive or Complimentary?

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Mechanical Advantages</strong></td>
<td>Boxes can be rotated due to standard structure &amp; connectors</td>
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<td>Early definition of system</td>
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<td></td>
<td>3-D symmetry gives strength and damping</td>
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<td>Cubes can be summed in x,y,z for larger size boxes</td>
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<td></td>
<td>Fixed attachment points for 3-D mounting</td>
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<td>Defined wiring channels between cubes</td>
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<td><strong>Modeling Advantages</strong></td>
<td>Rapid prototype models of satellite</td>
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<td></td>
<td>Simple and well defined x,y,z mechanical model</td>
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<tr>
<td></td>
<td>Simple and well defined x,y,z thermal model</td>
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<tr>
<td><strong>Electrical Advantages</strong></td>
<td>Common interface board defines common subsystem functions</td>
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<td>Greatly simplified wire harness (Motherboard)</td>
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<td><strong>Software Advantages</strong></td>
<td>Software defined early with common interface board</td>
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<td>Protocols for commanding and data defined by the common interface board</td>
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<td><strong>Systems Integration Advantages</strong></td>
<td>Common shake plate and thermal-vac attachments</td>
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<td>Rapid assembly and testing of electromechanical subsystems</td>
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<td><strong>Mass Production Advantages</strong></td>
<td>All mechanical boxes and lids symmetrical and quantized</td>
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<td>Storage of qualified modules for rapid assembly</td>
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Questions?

Visit our booth on the second floor for more information