USUSat III - TOROID

Tomographic Remote Observer of Ionospheric Disturbances

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Outline

• Mission Overview
• Spacecraft System Description
• Subsystem Description
• Program Description
Mission Overview

• Mission Statement
  – TOROID shall measure vertical profiles of the night time ionospheric plasma density distribution through tomographic reconstruction of extreme ultraviolet (EUV) night glow in the 1356Å emission band and demonstrate the use of key enabling technologies for small satellite success.

• Mission Highlights
  – Local Density measured using Plasma Impedance Probe
  – Photometer measures the intensity of 1356Å and 911Å EUV produced when free electrons recombine with oxygen ions
  – Tomographic reconstruction calculates vertical plasma density profile of the ionosphere

• Provides forecasting on scintillations on space borne communication systems

• Allows for real-time geolocation
Science Objectives

- **Equatorial Anomaly**
  - Fountain of plasma into high altitudes
  - Density drops, recombination slows, plasma lasts into night
- **Spread F (Scintillations)**
  - Bubbles form in lower plasma-no plasma interface, expand upwards
  - Occur 10:00 to 12:00 pm local time
  - Decreases signal to noise ratio in
    - Space communications
    - GPS signals
  - Bubble formation and evolution not fully explained
- **UV Tomography**
  - $1356\text{Å} \ 	ext{O}^+ + \text{e}^- = \text{O} + \lambda$
  - Rotating mirror and orbital velocity

- **Space based geolocation**
  - Signal path distorted by ionosphere
  - Accuracy requires knowledge of:
    - F-layer thickness
    - Density profile
    - Altitude
Science Objectives

- Transmitting satellite (Comm, GPS, etc.)
- Geolocation satellite
- Scintillation at gradients in plasma density
- Spread F Plume
- Distorted path length
- Night time ionosphere
- Scintillated Signal
- Receiver
- Transmitter of interest (Osama’s cell phone)
TOROID Bus

- TOROID’s structure is based upon the USUSat II bus
  - Retains heritage electronics and software from USUSat, structure from USUSat II.
- Uses capability driven, modular design
- The modular design of the USUSat II bus simplifies integration and test.
- A standard bolt pattern is machined into the structure
- Each module is assembled and harnessed individually. Harnessing between panels is limited to a single connector.
- Deck Panel
  - Honeycomb configuration provides lightweight, stiff deck
  - Ultrasonic Consolidation enables embedded features
TOROID Bus

Module 3
- CMOS camera
- Battery Box
- Solar Cells
- Antenna

Module Top
- Solar Cells
- Torquer Coil
- Reaction Wheel
- Sun Camera

Module 2
- CMOS camera
- Reaction wheel
- Solar Cells
- Antenna
- Torquer coil

Module 1
- (RAM)
- Solar Cells
- Antenna
- Payload
- Com. Units
- Reaction wheel
- Torquer coil
- Magnetometer

Module Bottom
- Downlink Patch, CEE box
- Ground connectors (RS232, Power), Lightband
System Organization

- Subsystems
  - Operations (05)
  - Structure (10)
  - Command & Data Handling (20)
  - Software (25)
  - Communications (30)
  - Ground Station (35)
  - Power (40)

- Ground Support Equipment
- Attitude Determination and Control (50)
- Mechanisms (60)
- Harness (70)
- Thermal (80)
- Science (90)
  - Includes both EUV Photometer and Plasma Impedance Probe
Structure

- Each panel designed for a modular configuration using standard bolt pattern
- Structure integrates several components, including CEE box, torque coils and Lightband interface
- Panels harnesses individually to an intra-module connector. This allows for easy integration and testing.
- Mass: 13.69 kg (w/ harness & fastners)
- Fabrication
  - 6 Panels directly machined through CNC
  - Internal Deck fabricated via additive manufacturing
- Material: Aluminum 6061
- Surface Finish: Irridite per MIL 5541

Integrated CEE Baseplate
Structure

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Closed Orthogrid with Skin
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Mechanisms

- Hinge
  - One way clutch
    - No locking energy
    - Zero backlash
    - Low cost
  - Torsion spring
    - Low stored energy
    - Safe for flight
  - Position switch
    - Informs ground station of the position of the antennas

- Release
  - COTS components
  - Low cost
  - No energy required to hold antenna in place
  - Few moving parts
  - Easily re-settable
Thermal

- Thermal environment determined
  - 185 km circular, 0° and 90°
  - 1000 km circular, 0° and 90°
  - Geotransfer Orbit
- Thermal model 95% complete
  - Addition of:
    - EUV photometer
    - Structural deck
    - Momentum wheel
- Thermal cases have been run
  - ~2.5 hrs for 9 orbits (transients damp out by 6th orbit)
  - Surface properties for good radiative balance have been determined
  - Optimal thermal conductances for battery have been determined
Command & Data Handling

• Physical Characteristics
  – Main components
    • Hitachi SH3 7709 Microprocessor
    • VxWorks Operating System
    • Actel 42MX FPGAs
    • 256 KB EEPROM
    • 6 MB SRAM
    • 32 MB Flash Memory
  – Interfaces w/ other subsystems through CEE backplane and various top connectors
  – System broken up into specialized boards
  – Specialized I/O board extends CPU capabilities

• Performance Characteristics
  – Fault tolerant hardware and software design
  – 32-bit 80-MIPS processing power
  – 64 ADC channels
  – 71 Digital inputs/outputs
  – Two RS232 and one RS422 port
  – An SPI bus able to connect up to 16 devices
  – 1-Wire® bus
  – DMA oriented telemetry and camera image buffers
Software

- Software overlooks:
  - Execution of mission operations.
  - Coordination amongst various subsystems to provide a fully functional system.
- Operation can be classified into:
  - Operating System Software
  - Control System Software
  - Data Collection/Manipulation Software
  - System Management Software.
Software
Communications

- **Data Link**
  - L-3 ST802-S Transmitter
  - Patch Antenna
- **Command Link**
  - Terminal Node Controller
    - Encodes/Decodes data in AX.25 ver 2.0 packets
    - Controls Radio and reduces CPU processing load
    - Programmed into PIC18F452
  - TEKK KS-960-L Data Radio
    - Analog radio
    - Separate Tx and Rx frequencies
    - Oscillator is temperature stabilized

- **Splitter Board**
  - Student Designed and Built
  - Divides signal from radio into four equal signal
  - Uses High Isolation switch to allow one antenna to be shared as science probe

- **Deployable Antenna Array**
  - Nearly Omnidirectional
Power

- **Power Control**
  - DC/DC Converters +/- 3.3V, +/-5V, -12V, 24V, 12 and 10 V Regulators.
  - Charge control: by monitoring battery voltage and temperature.
  - Includes SEL Mitigation for CPU
- **Solar Cells**
  - Triple Junction GaAs solar cells, 24% efficiency, Surface mounted on 5 faces
  - Solar cells will be attached in accordance with AA-21102-doc01-2 that contains the step-by-step assembly procedure for solar cells approved by AFRL.
- **Safety Inhibits**: Follows the recommendations from NSTS1700.7B, unpowered bus exception 3 fault tolerant inhibit scheme.

- **Grounding**: All boards are grounded to the satellite chassis through the backplane.
- **Battery**
  - NiCd Type (Sanyo N-4000DRL), 1.2 Volt per cell, 13.2 Volt nominal bus.30V, 4 A-hr Battery
  - Enclosed in a battery pack built to NS4 safety specifications
Attitude Determination & Control

- TOROID uses momentum bias stabilization. The feature of momentum bias is that it can provide roll-yaw dynamic coupling, providing an accurate yaw control without a direct yaw sensor, hence it is simple and reliable.

- Sensors
  - Three axis fluxgate magnetometer
  - CMOS cameras used as sun sensors and star imager

- Actuators used for control are:
  - Momentum wheel
  - Magnetic torque coils
Science

• EUV Photometer
• Detects EUV intensities for tomographic reconstruction of the full *vertical* plasma density profile
  – Rotating mirror directs light to sensor
  – Microchannel sensor counts photon hits
  – Photon counts collected for EUV intensity
  – Data is downlinked for tomographic reconstruction
• Mirror is narrow bandpass filter
Ground Station

- **Ground Station Hardware**
  - 4.5m Parabolic Antenna and Yagi Array antenna
  - Kenwood TM-700D Tranciever
  - Microdyne 700 receiver

- **Ground Station Software**
  - USUSAT will be adapting the MercuryGS software package for real-time data display and command interfaces.
  - The operating system for the ground station is the GNU Debian Linux distribution.
  - Software tracking as required by S2.35-2 is being implemented through the Predict software server package and the Satellite Tracker Jr. hardware control interface.

- **Ground Station Controller**
  - Controls both Data link and Command Link antennas
  - Integrates auto-tracking capabilities
## Schedule

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Facilities

• “Design Space”
  – Mechanical Lab
  – Electrical Lab (“Bat Cave”)

• Clean Room
  – Class 100,000
  – Located in TOROID Mechanical Lab

• RF – Anechoic Chamber
  – Measure antenna patterns
  – S-band system tests

• ADCS – Helmholtz Coils
  – Simulate orbital magnetic field
## Personnel

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<tr>
<th>Sub-system</th>
<th>Name</th>
<th>Students Major</th>
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<tr>
<td>Program Manager</td>
<td>Jared Clements</td>
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<td>Systems Engineer</td>
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<td>Dan Swenson</td>
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