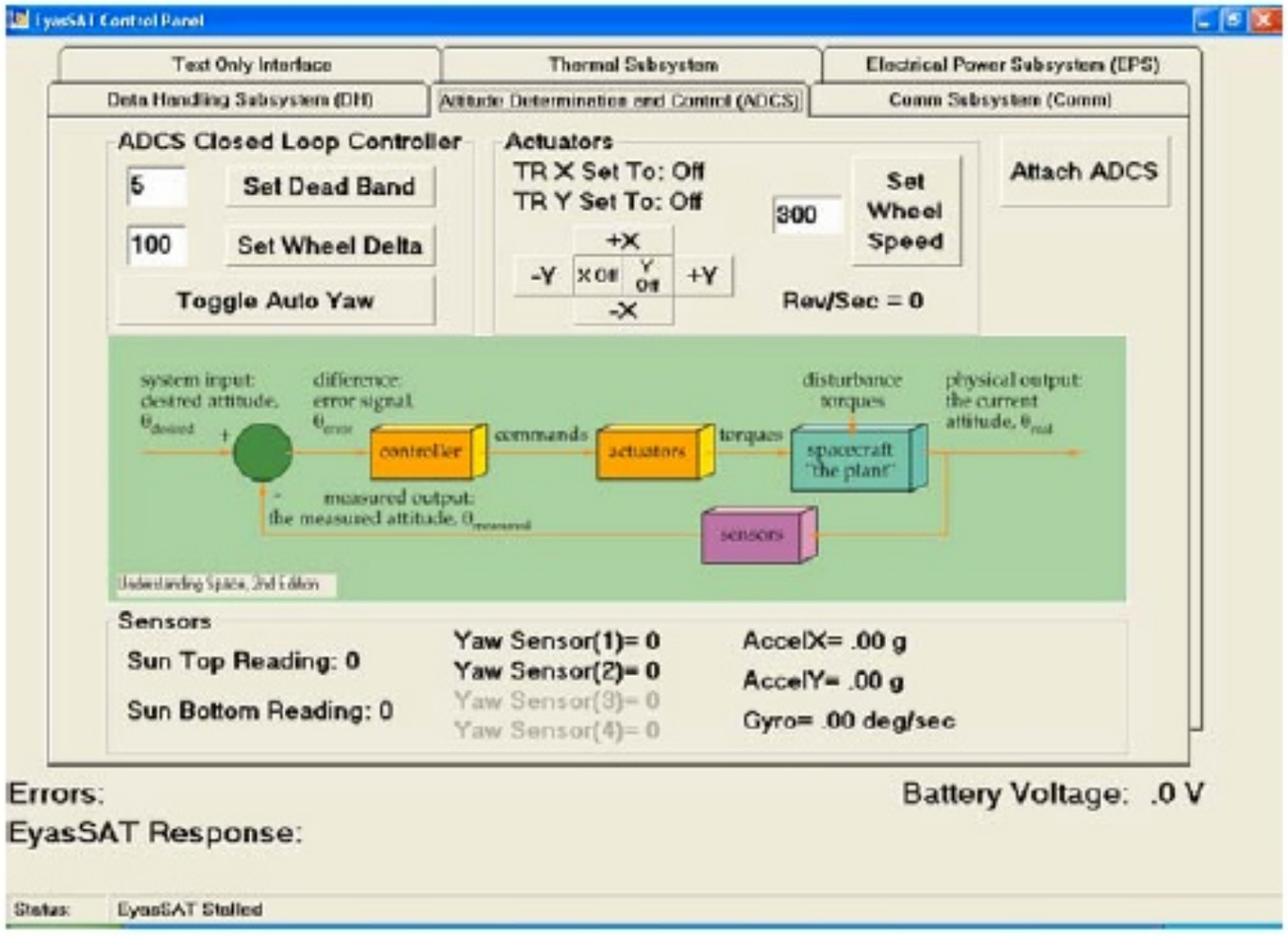
EyasSAT: A Classroom Nanosatellite for Teaching Space Systems Engineering



Outline

- Introduction
  - The Need
  - The Solution
- Background
- EyasSAT System Architecture
- EyasSAT Applications
- Conclusions

The Need

- Space Systems Engineering is a complex discipline that spans the full life-cycle of all space programs, from Mega to Nanosats.
  - Traditionally, space systems engineers first gained expertise in a specific domain, such as astronautical or electrical engineering, then learned how to apply that expertise to different phases of a projects through on-the-job training.
  - Unfortunately, as the life-cycles for major programs stretch into decades, and as engineers move from project to project, there is less and less opportunity to gain hands-on system-level experience from design through operations.
  - A further limitation on gaining hands-on experience is the cost, complexity and scarcity of flight hardware. Increasingly, space projects have adopted a proto-flight approach to flight hardware whereby only a single flight article is built, tested and launched.
- Thus, there is little opportunity for budding space systems engineers to get their hands on hardware and software.

The Solution

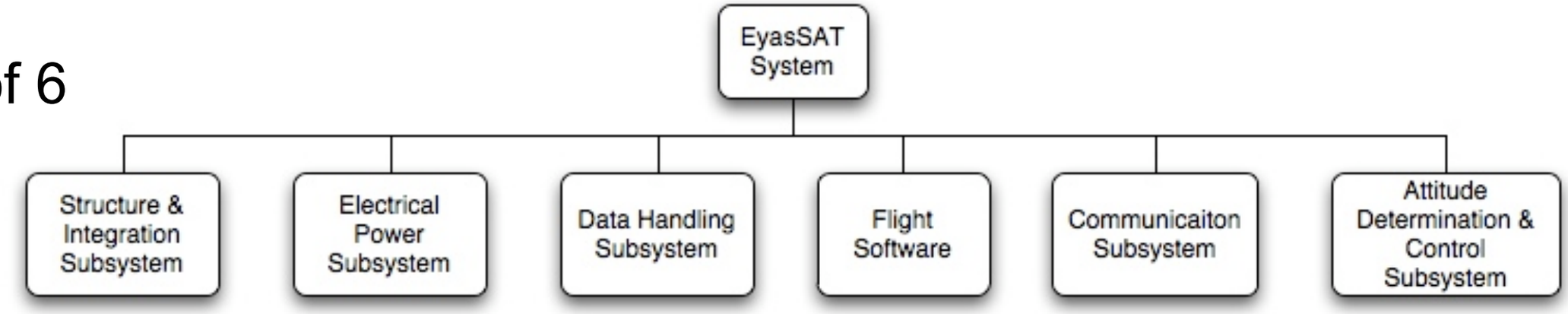
- Recognizing these fundamental limitations, engineers at the USAF Academy, in cooperative effort with industry, design and built the EyasSAT™ Educational Satellite System.
  - EyasSAT enables a revolutionary approach to teaching space systems engineering by giving students the opportunity to:
    - » 1) review and analyze the design from basic need through detailed drawings;
    - » 2) verify each subsystem against a set of design requirements;
    - » 3) integrate the entire system;
    - » 4) perform system-level verificaiton and validation procedures;
    - » 5) “fly” the satellite through RF-based ground system.
- This presentation will
  - Review the background on EyasSAT,
  - Describe its system architecture
  - Give examples of how EyasSAT is being used to teach space systems engineering at the USAF Academy, NASA and ESA over the last four years.

Background

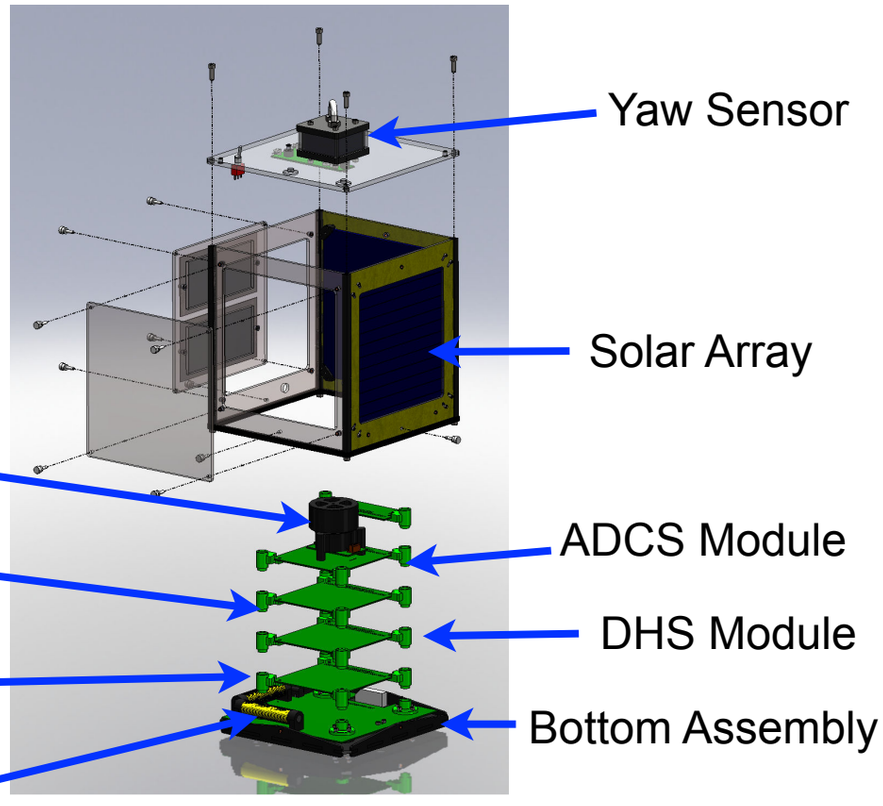
- EyasSAT is a fully functional nano-satellite designed for teaching spacecraft systems engineering in the classroom and laboratory.
  - The name “EyasSAT” has its roots in falconry, an “eyas” is a “baby falcon” or “fledgling bird.”
  - The falcon is the mascot of the US Air Force Academy, where the concept for EyasSAT was hatched.
- EyasSAT was co-developed under a Cooperative Research and Development Agreement (USAF CRDA NUMBER 04-AFA-239-1, 25 August 2004) by the U.S. Air Force Academy, Colorado, USA and Colorado Satellite Services, Parker, Colorado, USA.
  - This concept and the embodiment of the idea have been submitted for U.S. patent consideration and is currently in the “patent pending” status. Current information on the EyasSAT program can be found at http://www.eyassat.com

EyasSAT Physical Architecture

EyasSAT is composed of 6 subsystems

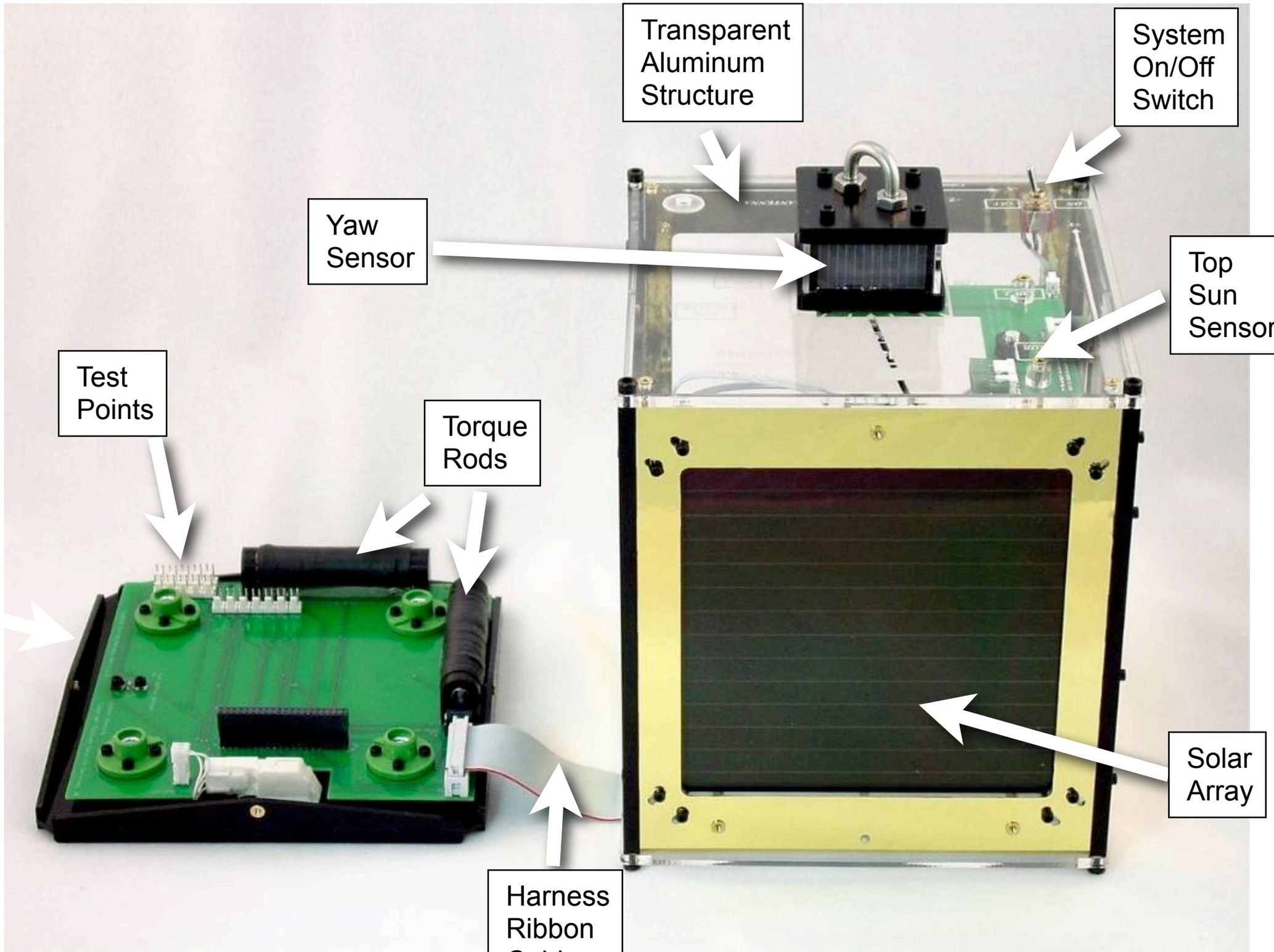


EyasSAT Integration



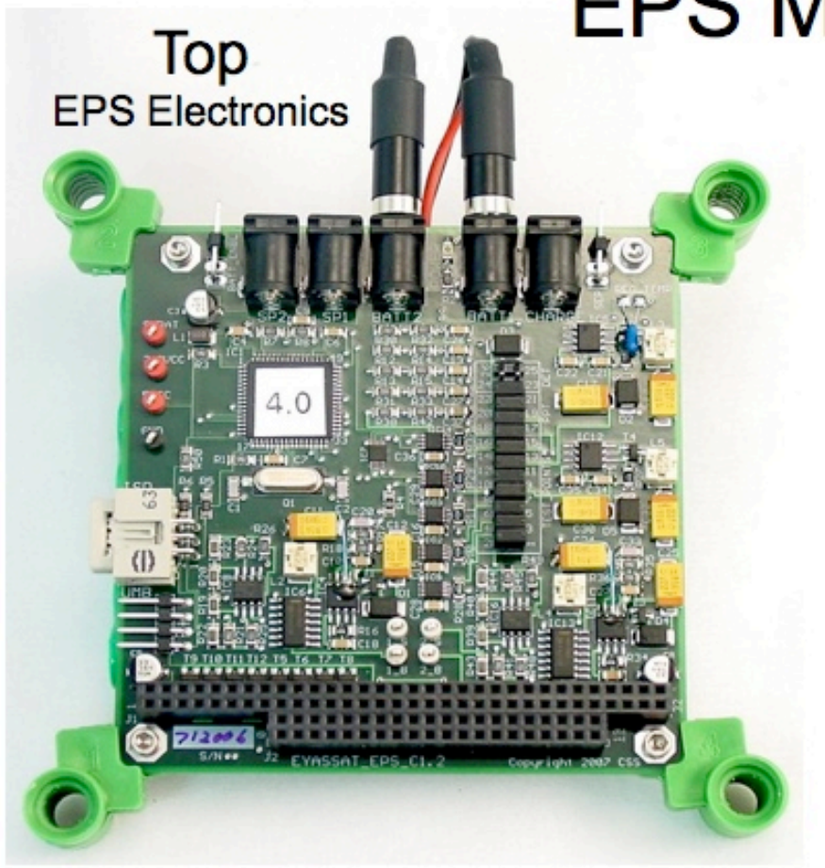
EyasSAT Fully Assembled

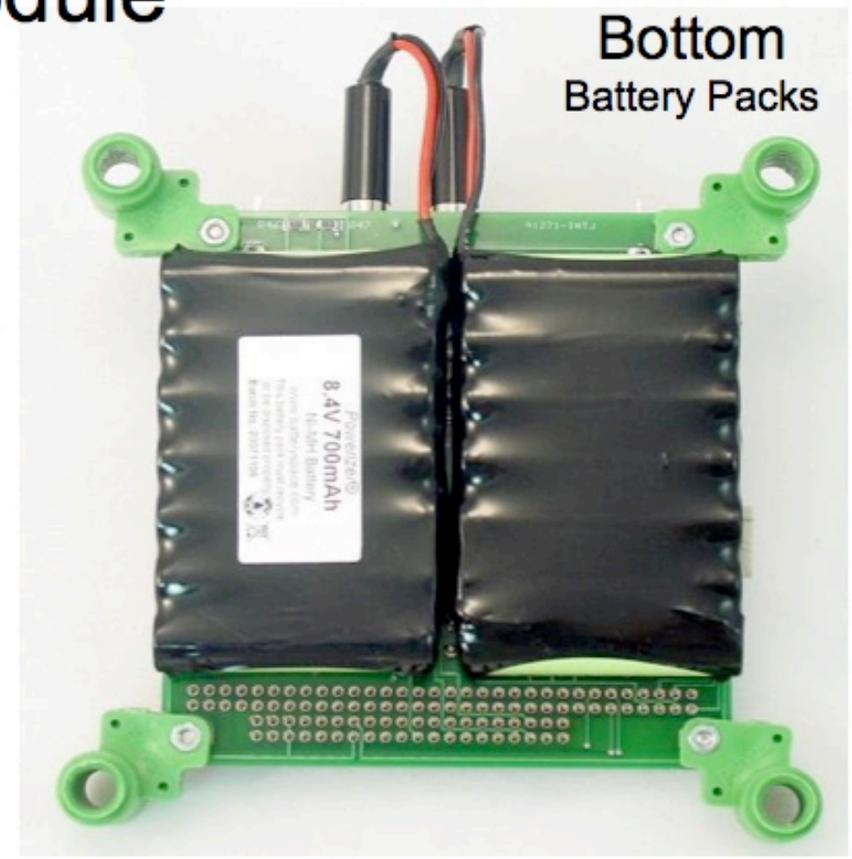
Structures & Integration Subsystem (SIS) Hardware

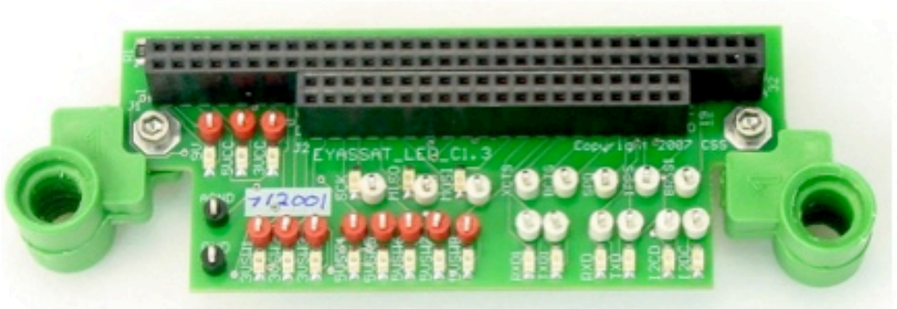


EyasSAT EPS Hardware

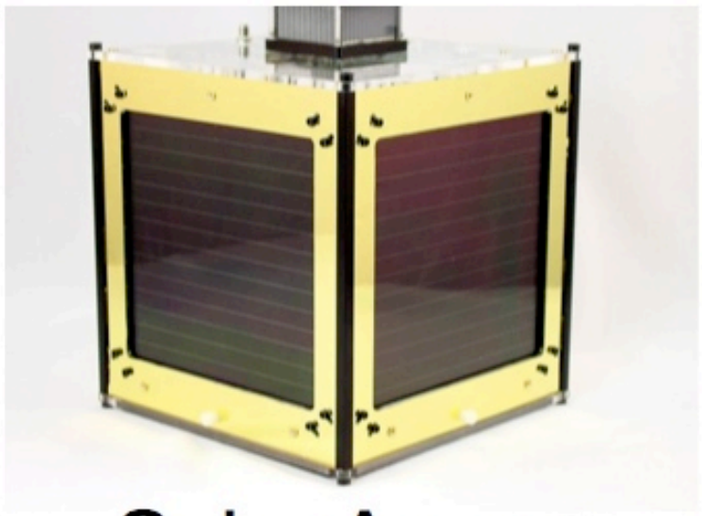
EPS Module





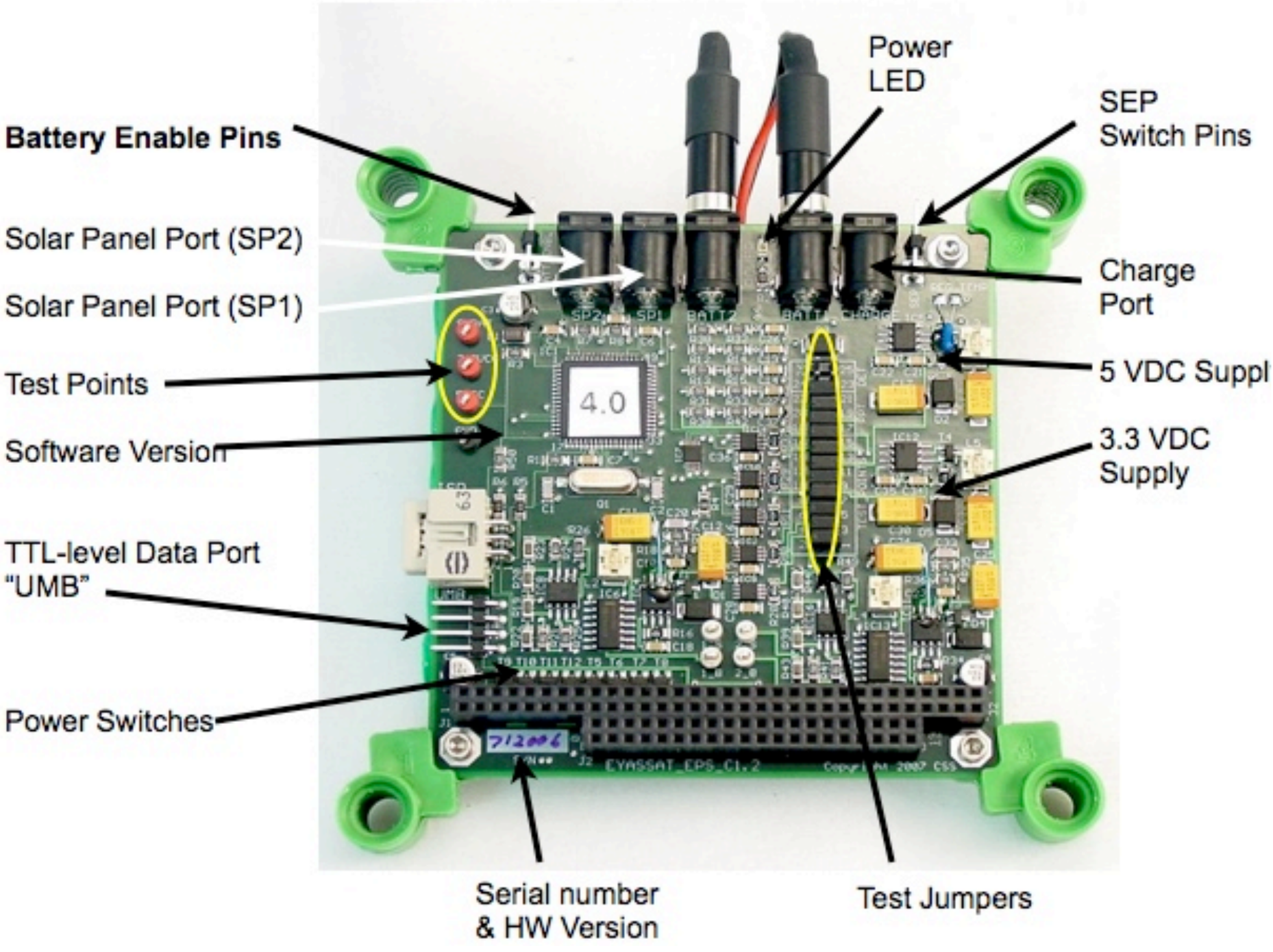


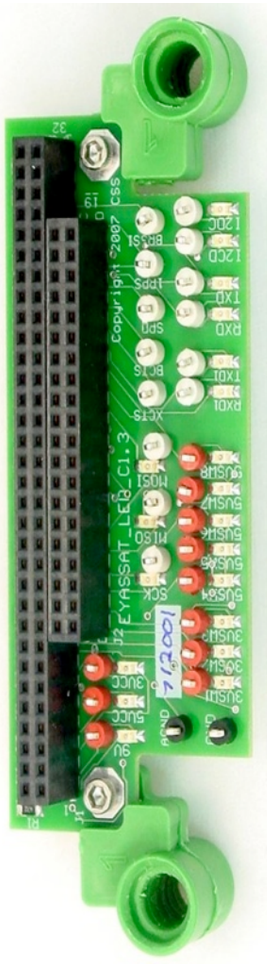
LED Test Module



Solar Arrays

EPS Module/LED Test Module

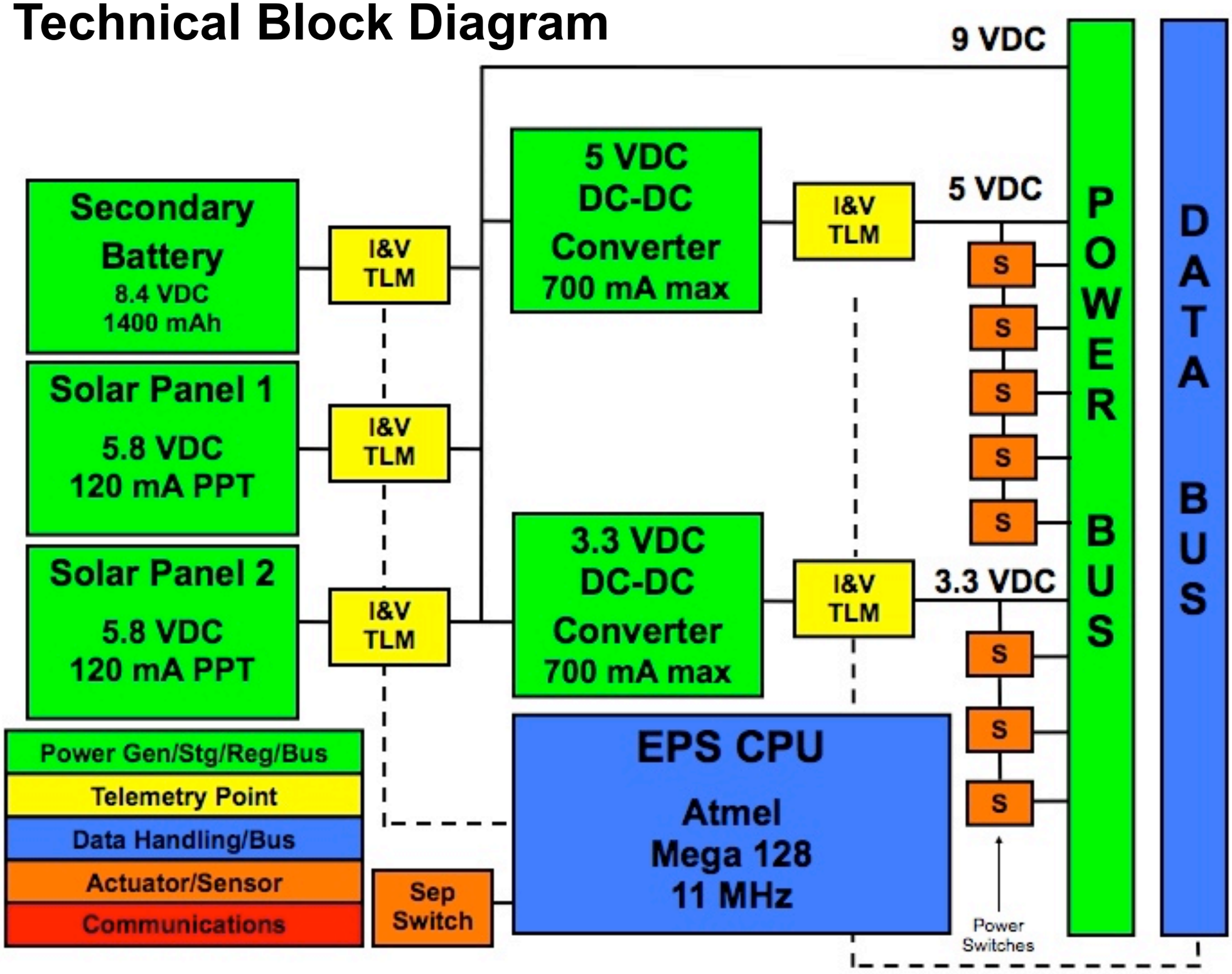




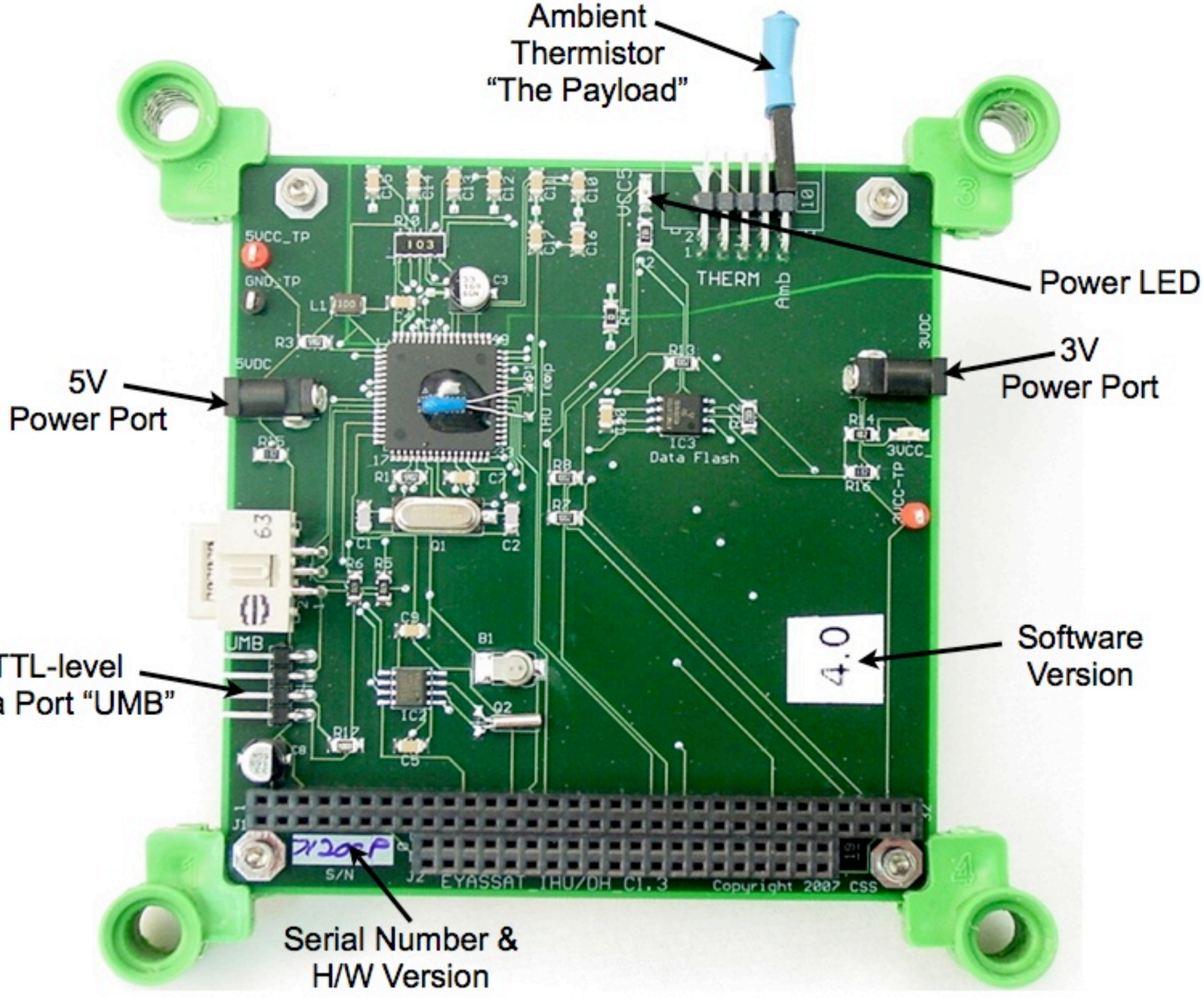
LED
Test Module

EyasSAT Electrical Power Subsystem (EPS)

EPS Technical Block Diagram

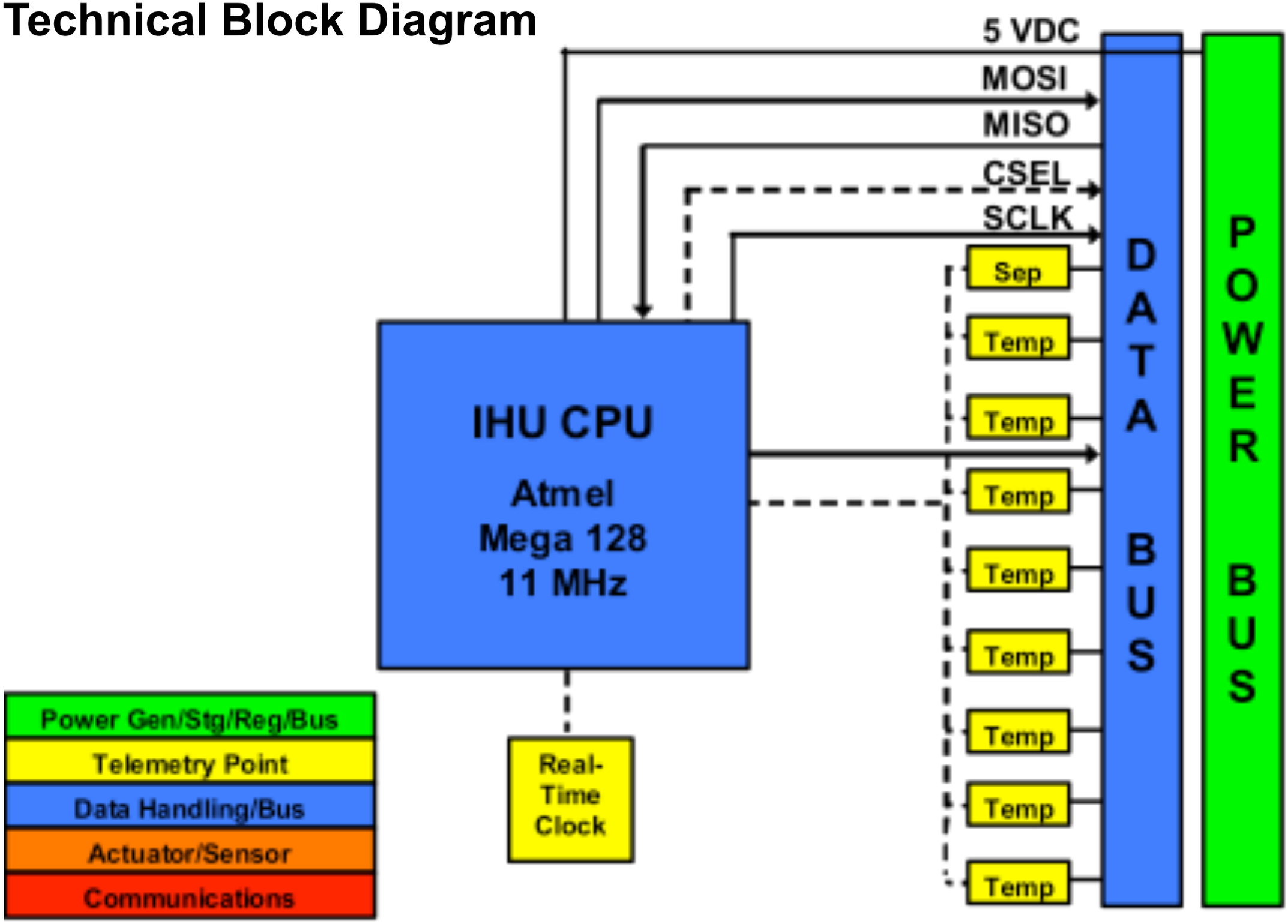


Data Handling Subsystem (DHS) Hardware

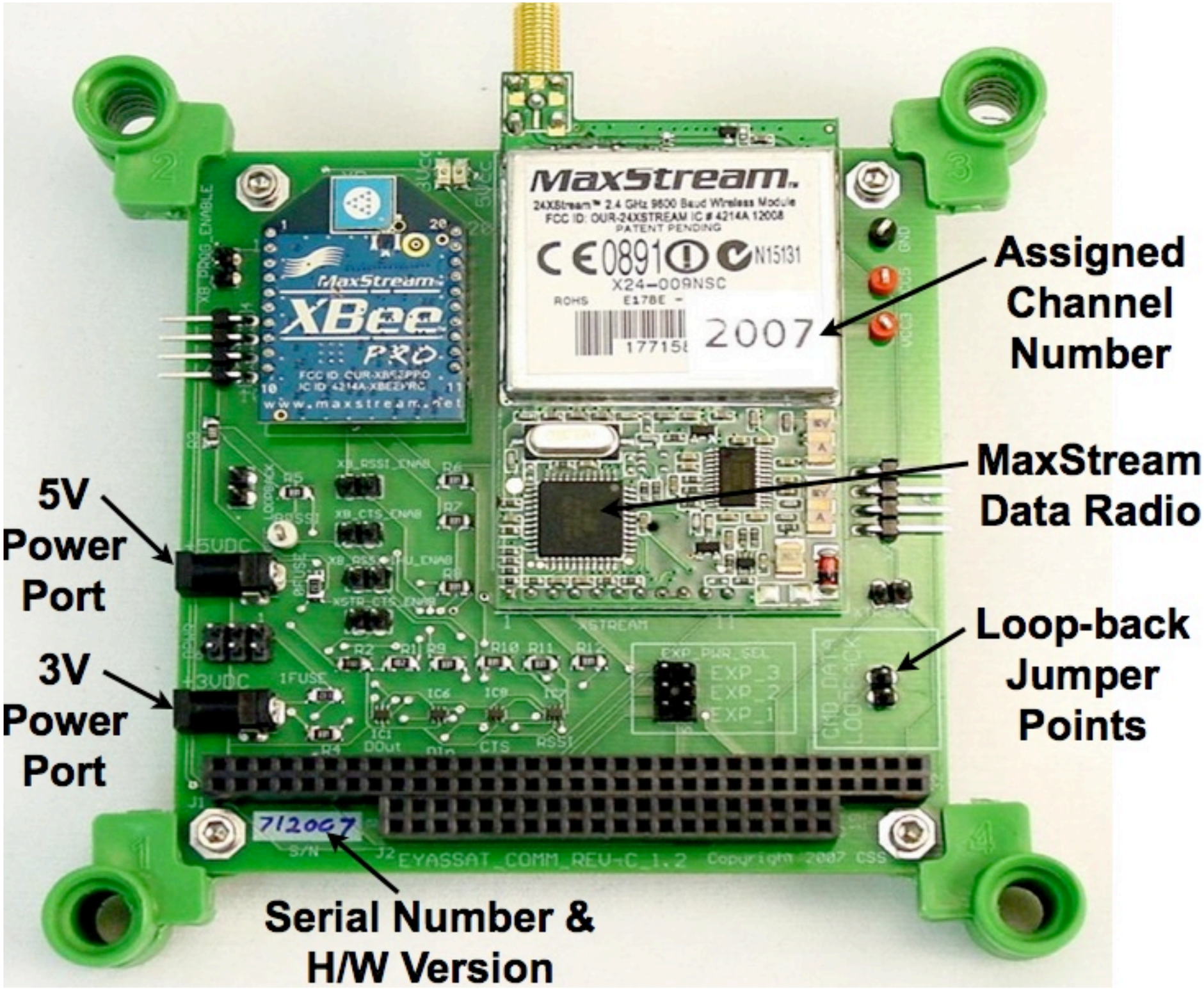


DHS Module

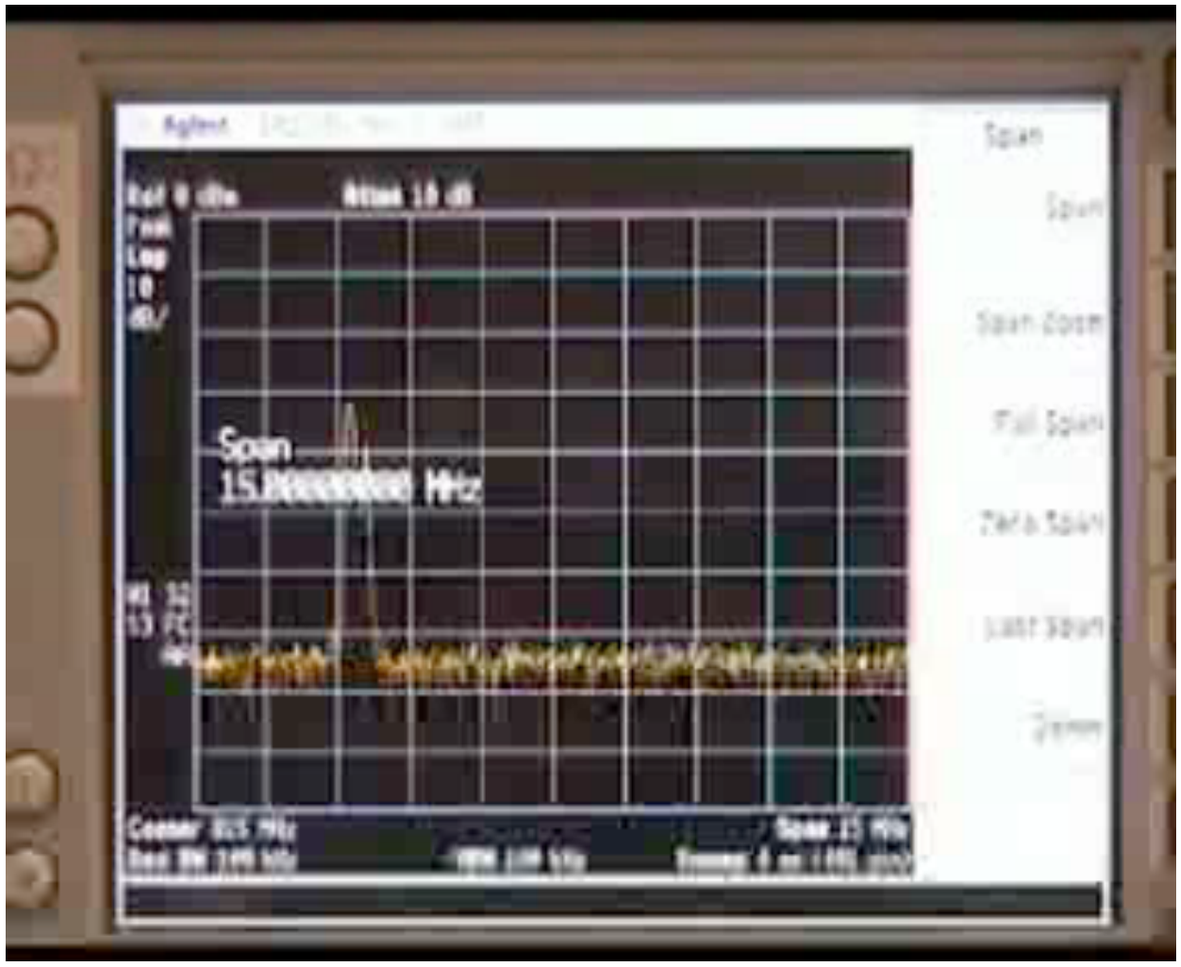
DHS Technical Block Diagram



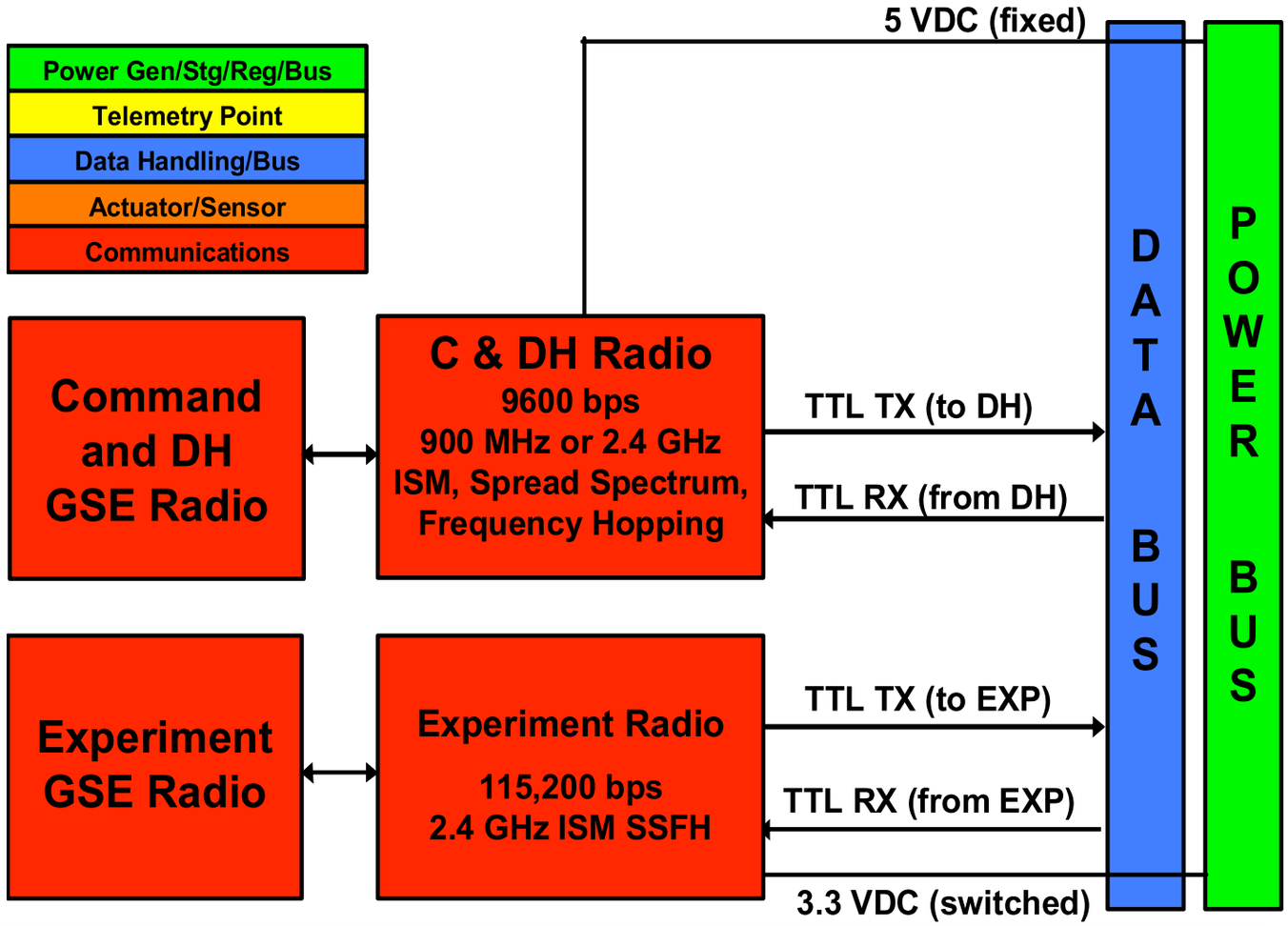
EyasSAT Comm Subsystem Hardware



EyasSAT Comm Subsystem
Hardware and Block Diagram



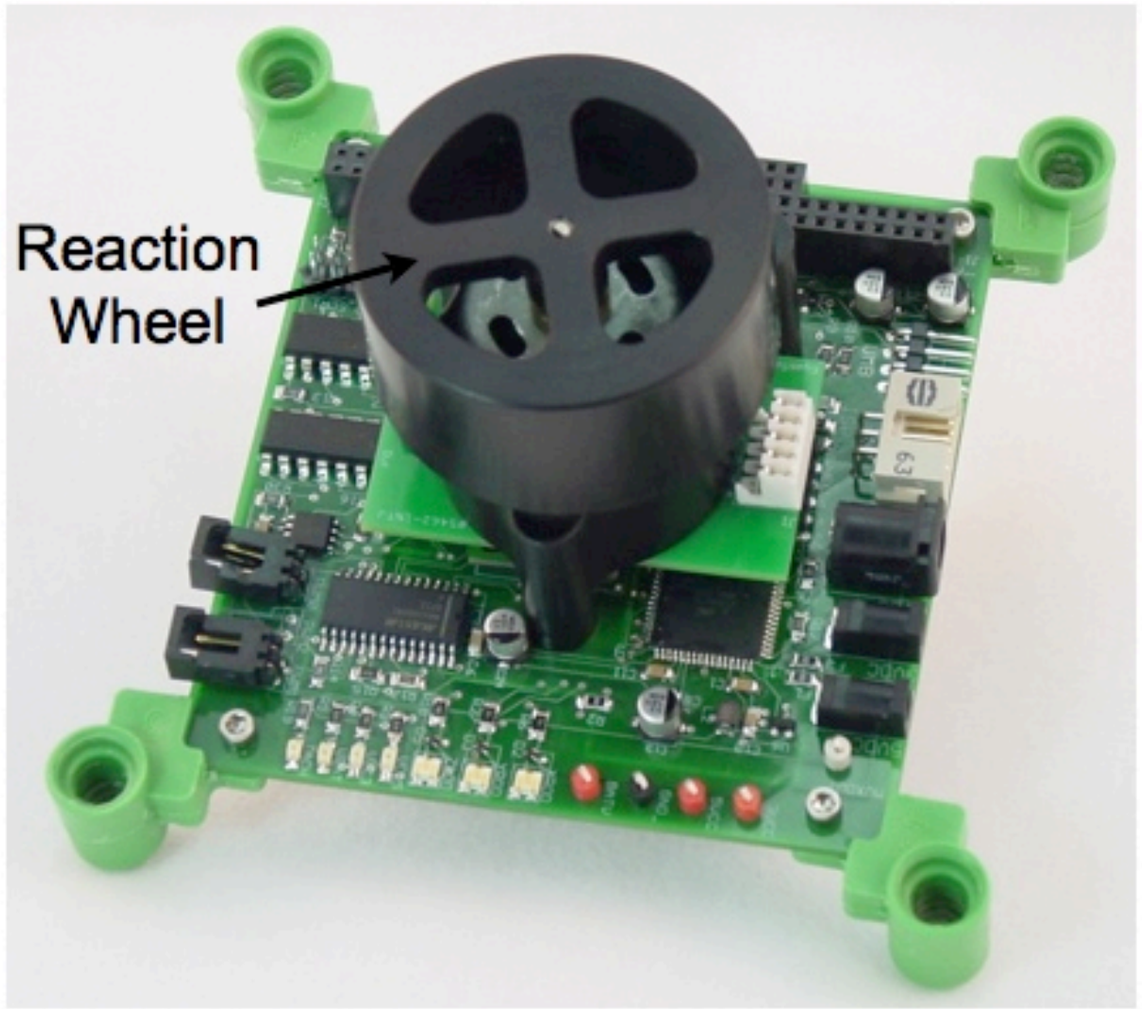
Spectrum Analyzer view of EyasSAT Frequency Hopping



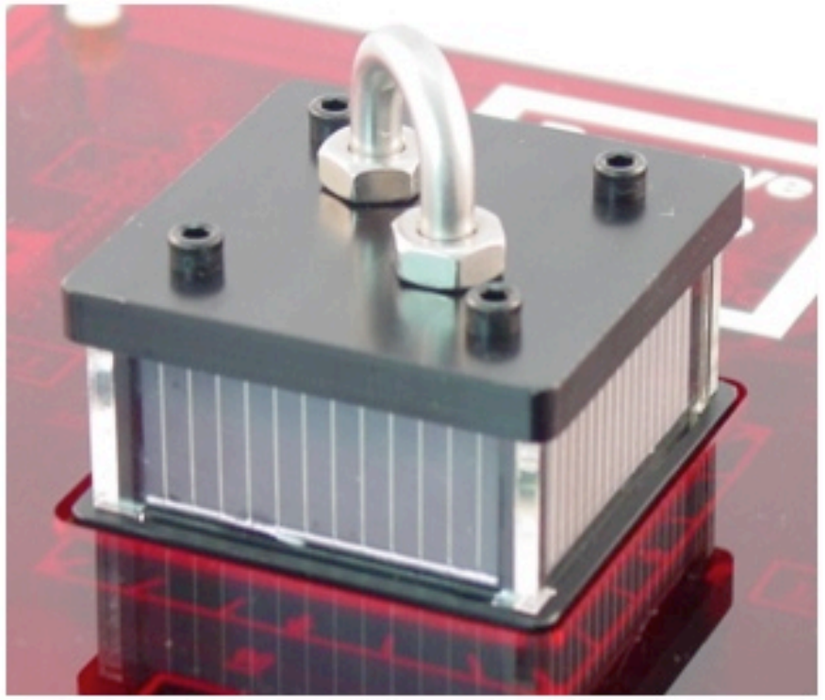
DHS Technical Block Diagram

EyasSAT ADCS Hardware

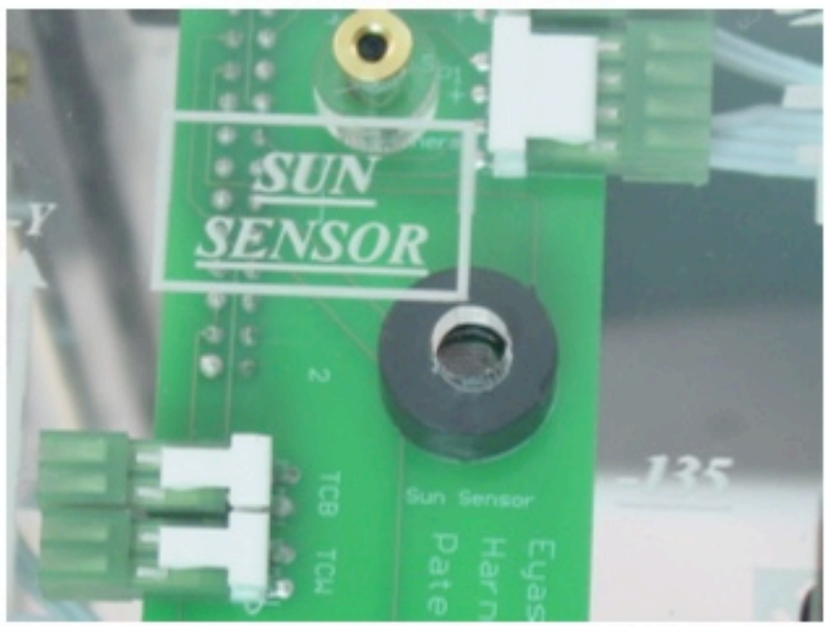
ADCS Module



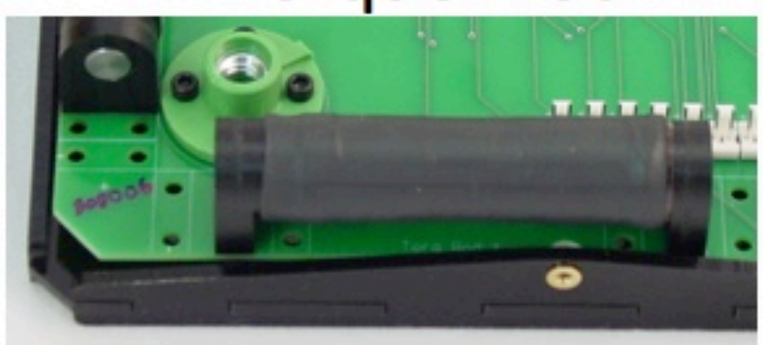
Yaw Sensor



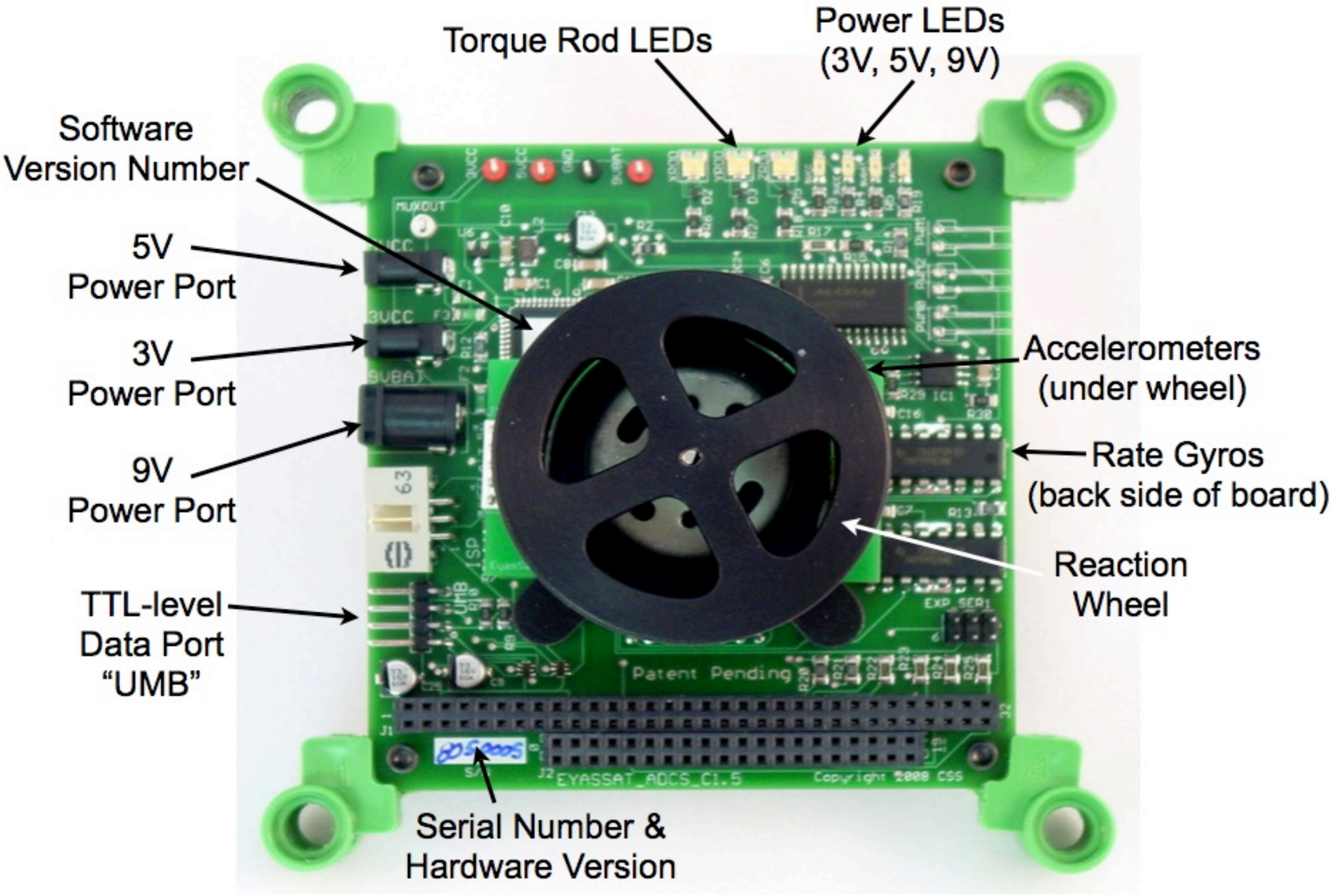
Sun Sensor



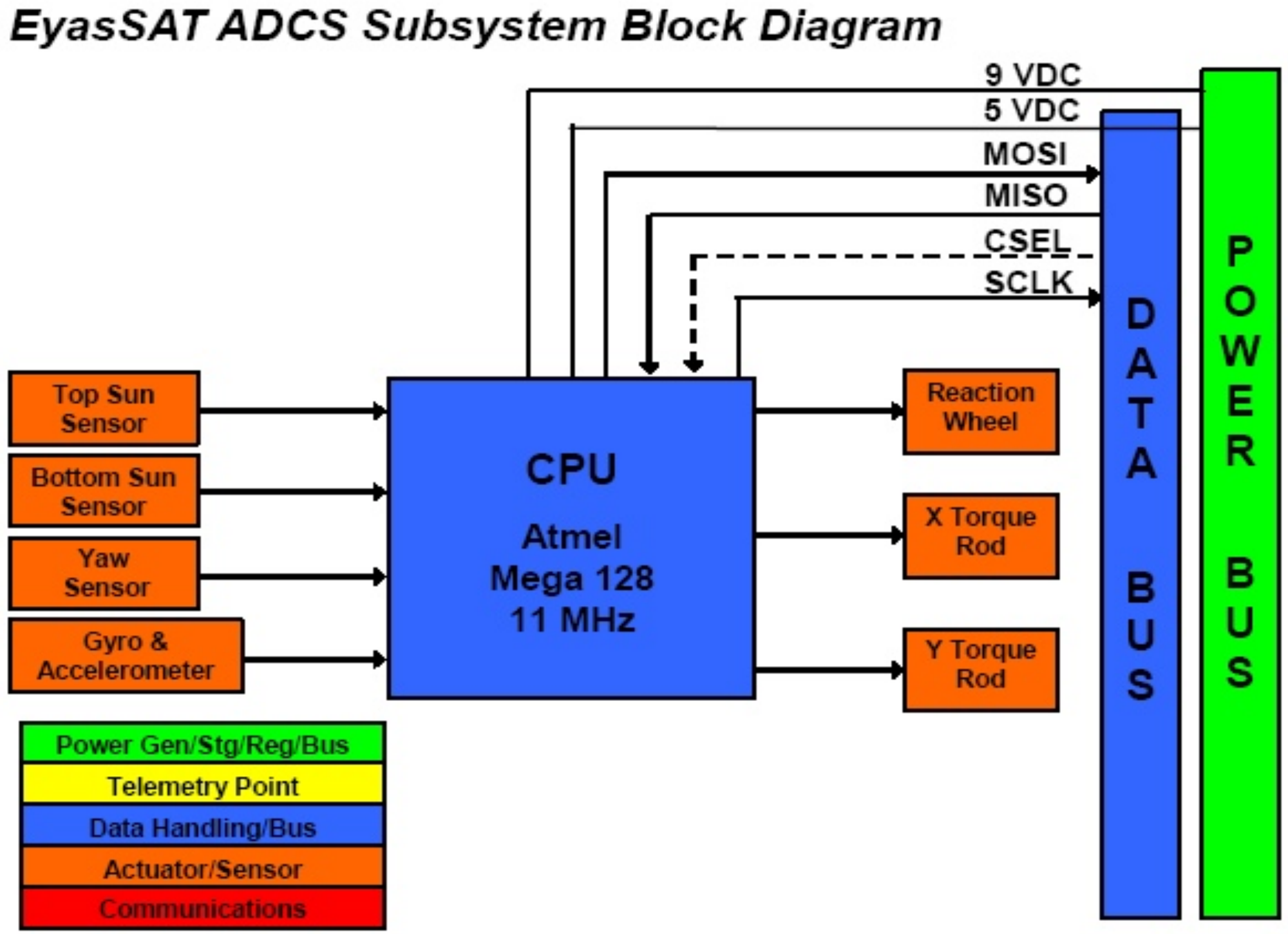
Torque Rod



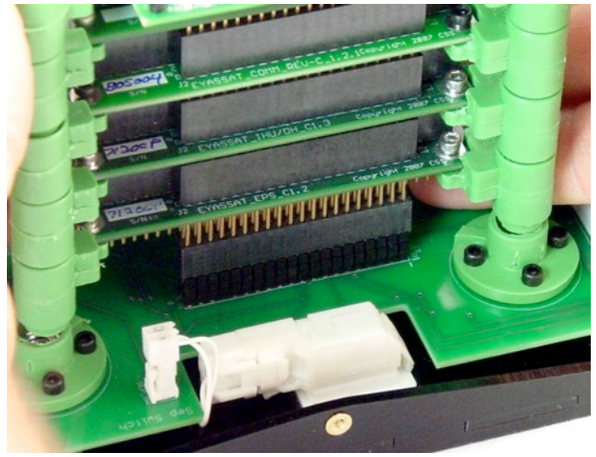
ADCS Module

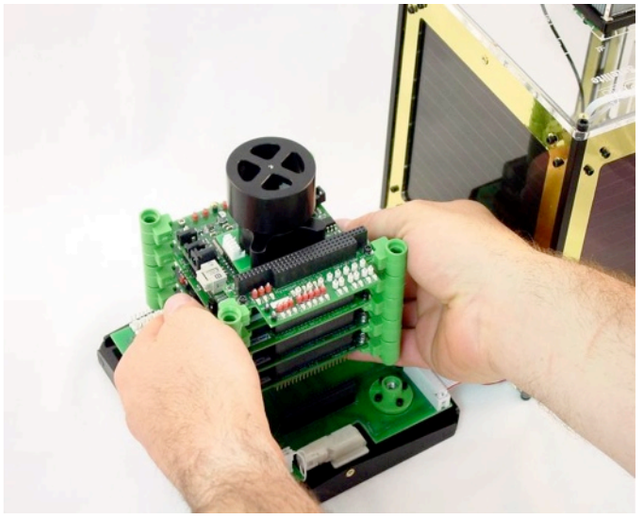

Torque Rod LEDs
Power LEDs
(3V, 5V, 9V)
Software
Version Number
5V
Power Port
3V
Power Port
9V
Power Port
TTL-level
Data Port
"UMB"
Accelerometers
(under wheel)
Rate Gyros
(back side of board)
Reaction
Wheel
Serial Number &
Hardware Version
Patent Pending
EYASSAT_ADCS_C1.5
Copyright 2008 CSS

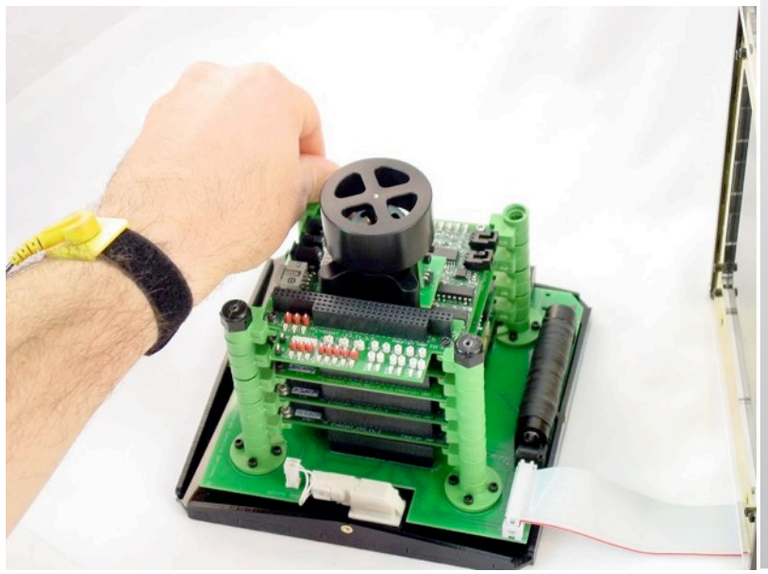
EyasSAT ADCS Block Diagram

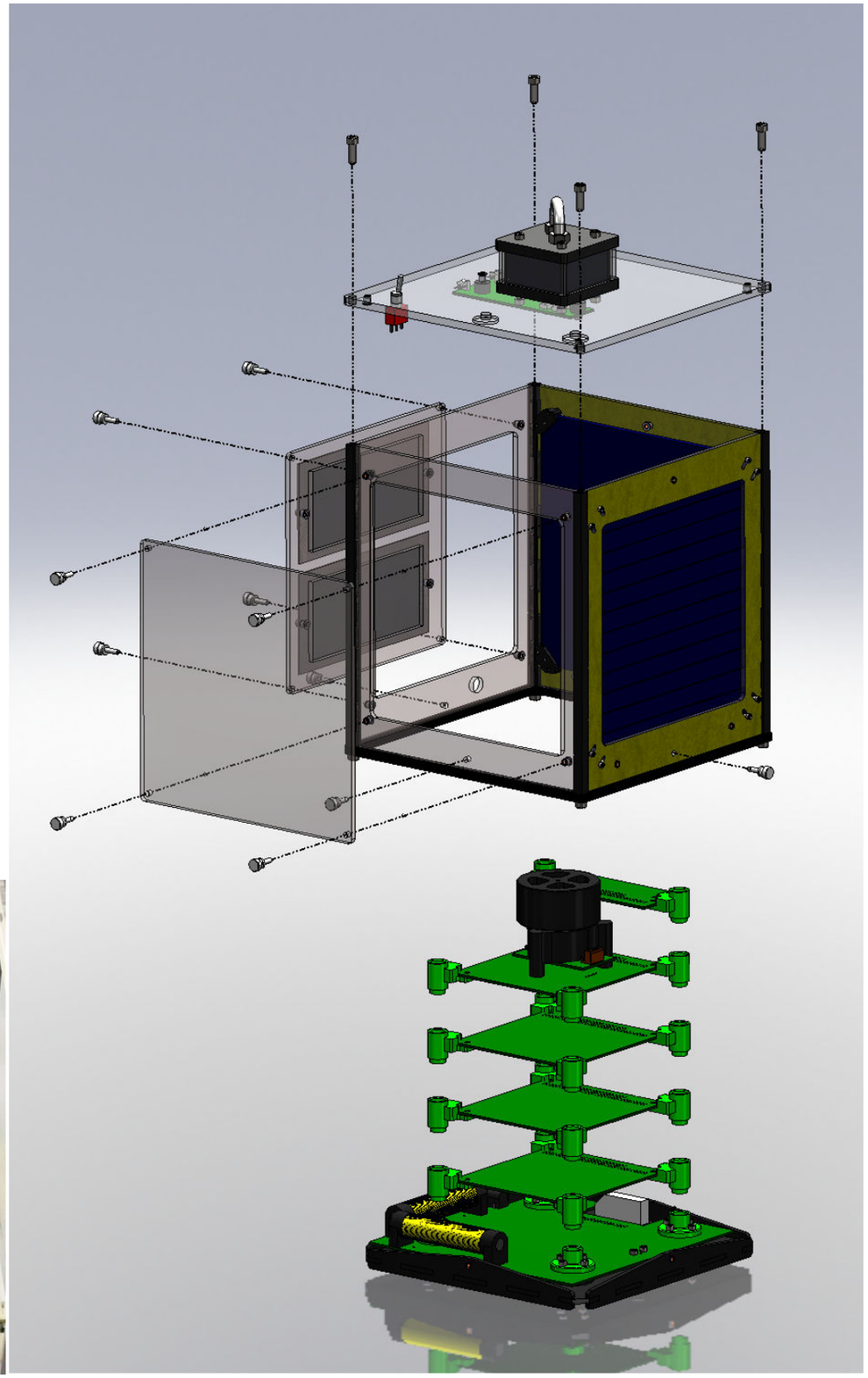


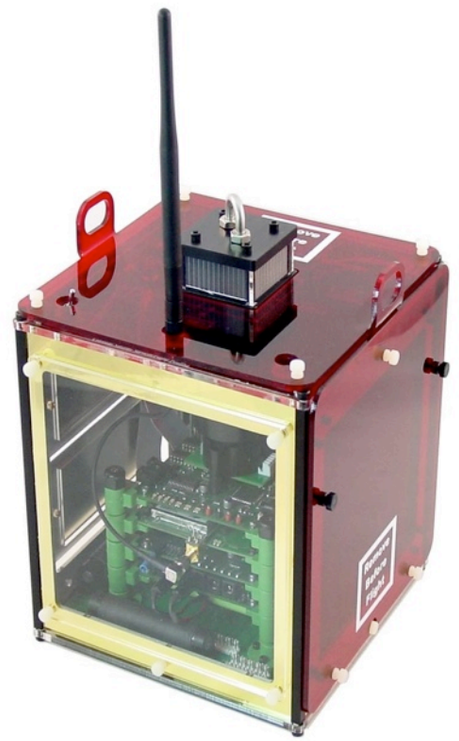
EyasSAT Assembly







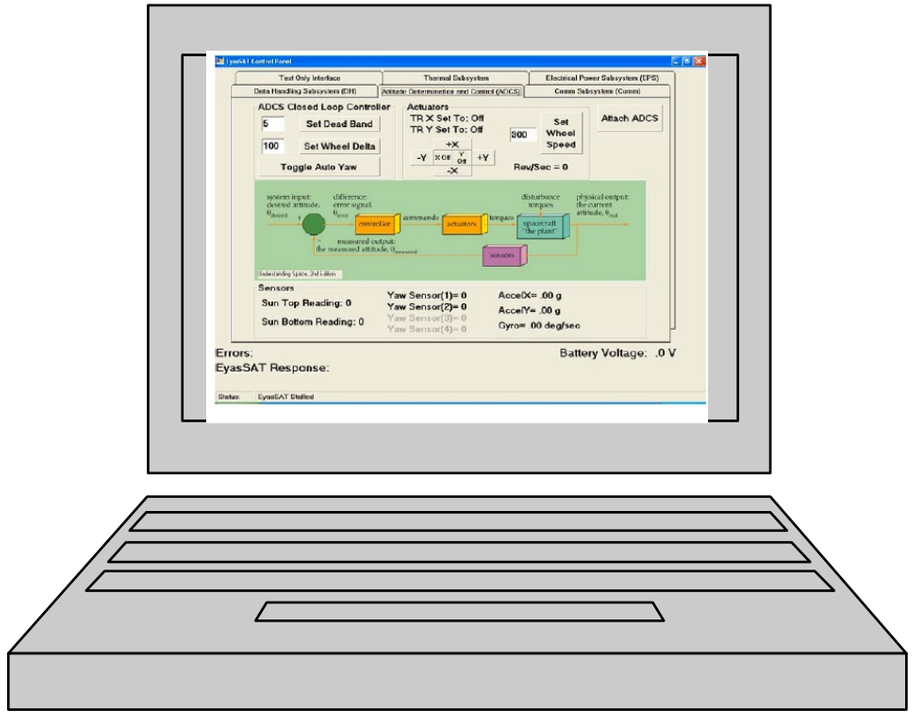




EyasSAT Operations System Configuration

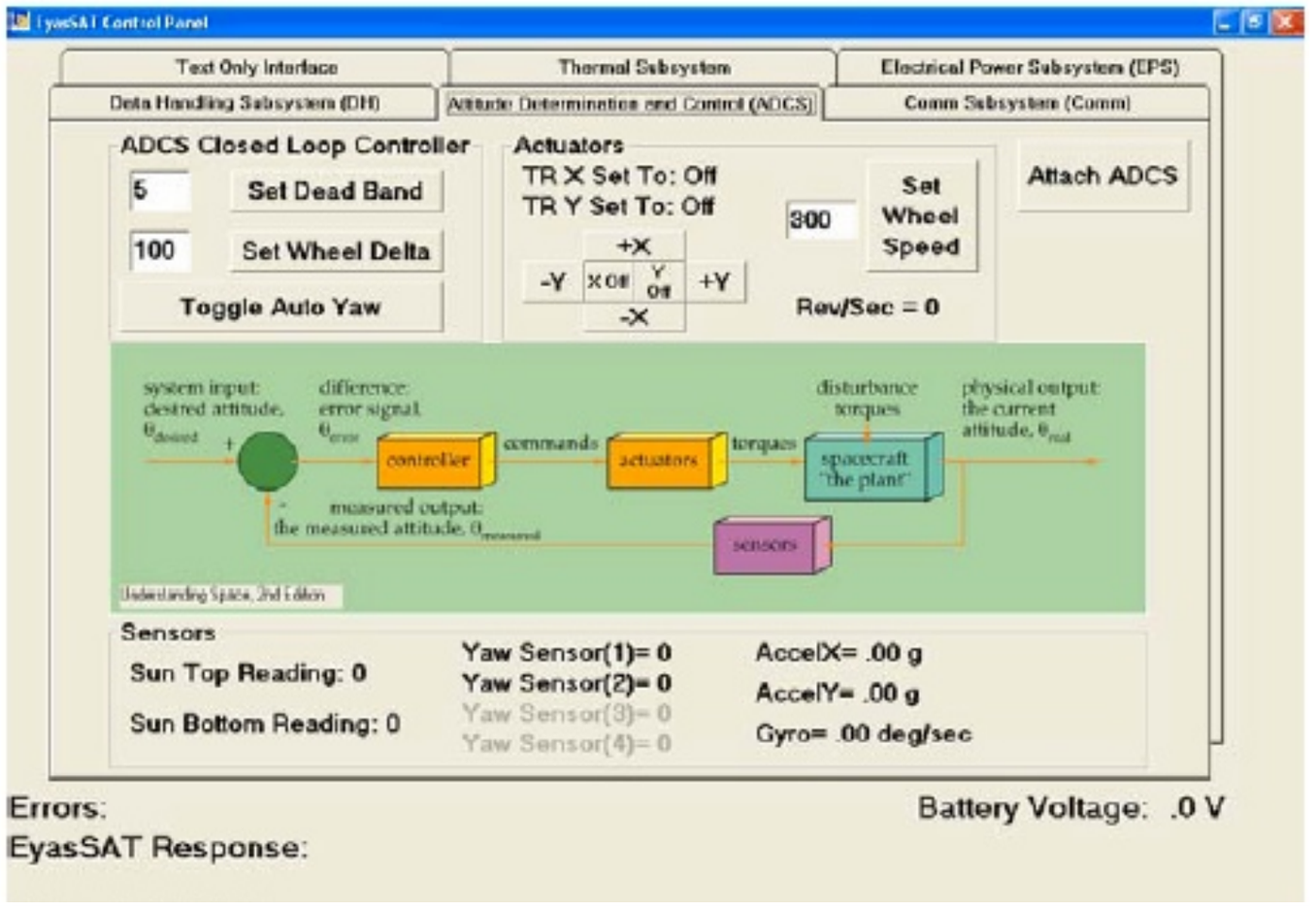
Port for RS-232 cable to computer

EyasSAT Ground Station Transmitter/Reciever



EyasSAT C2 Laptop

EyasSAT C2 Software



EyasSAT Applications

- Primary Education
  - Andoy High School, Norway
- Undergraduate Education
  - USAF Academy
  - Georgia Tech
  - Carlton Univ., Ottawa, Canada
  - Shun King Univ. Taiwan
- Graduate Education
  - Stevens Institute of Technology
- Industry
  - Microsat Systems Inc.
- Government
  - NASA
  - ESA
  - AF Space Command

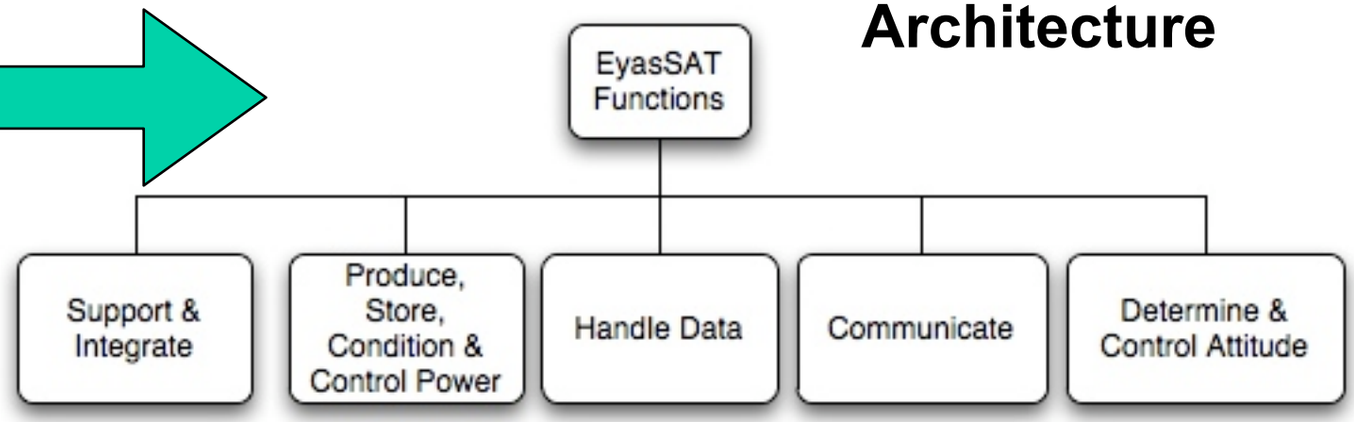
EyasSAT is being used in a wide variety of training and education courses, as well as applied research throughout the industry

Example: Systems Engineering Scope

Required System Characteristics & Capabilities

- Form--System Characteristics "what it shall ***be***"
- Fit--System Interfaces "what it shall ***connect to***"
- Function--System Capabilities "what it shall ***do***"

Functional Architecture



Systems Engineering leads us from Requirements to Design to V&V.

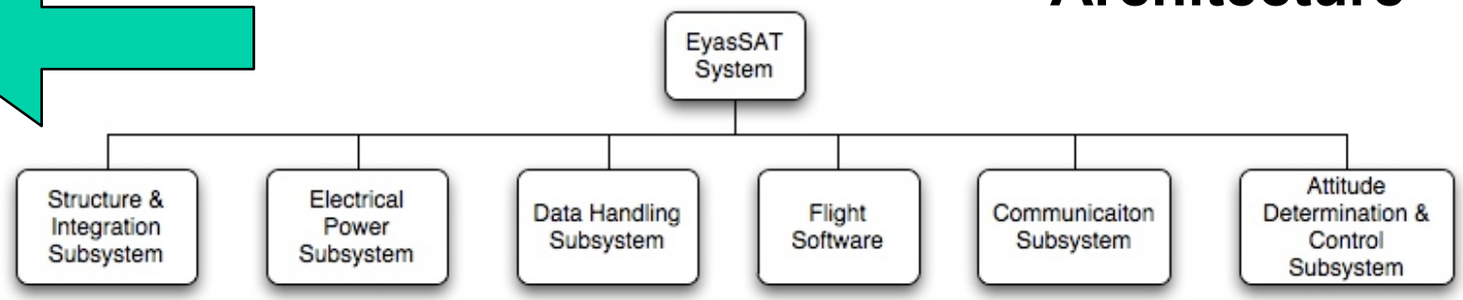
V&V "Closes the Loop" between what we *want* and what we *got*

V&V Planning

EyasSAT Requirements Verification Matrix

REQUIREMENT	VERIFY METHOD (LEVEL)	EVENT(S)	SUCCESS CRITERIA	D ...?	VERIFY STATUS?	COMMENTS
***3.1 System Characteristics*: EyasSAT System characteristics shall be as refined by the following:**	Inspection (SYSTEM)	System Acceptance Review	If verification of all characteristic requirements have been successfully completed.			
3.1.1. System Definition: EyasSAT system major components shall include the following: (1) Structure & Integration Subsystem (SIS, (2) Electrical Power Subsystem (EPS) Module, (3) Integrated Housekeeping data Unit (IHU) Module, (4) Communication Module (Comm), Attitude Determination & Control Subsystem (ADCS) Module, LED Test Module	Inspection (SYSTEM)	System Baseline Physical Inspection	If all specified major components are included			
3.1.2. System Mass: Total system mass shall not exceed 3.0 kg, Subsystem mass is allocated as follows:	Inspection (SYSTEM)	System Baseline Physical Inspection	If system mass does not exceed 3.0 kg.			
3.1.2.1 SIS Mass: SIS mass shall not exceed 1.5 kg.	Inspection (SUBSYSTEM)	SIS Baseline Physical Inspections	If SIS mass does not exceed 1.5 kg			
3.1.2.2 EPS Mass: EPS Module mass, including LED Test Module, shall not exceed 0.5 kg.	Inspection (SUBSYSTEM)	EPS Baseline Physical Inspections	If EPS mass does not exceed 0.5 kg			

Physical Architecture



Example: EyasSAT System Requirements

- 3.1 System Characteristics
  - System Definition (e.g. major component list)
  - System Mass, Moment of Inertia
  - Dimensions
  - Materials, Workmanship, Markings, Sharp Edges
  - Maintainability, Transportability
- 3.2 System Interfaces
  - Internal (subsystem to subsystem)
  - External (system to Ground Support Equipment)
- 3.3 System Capabilities
  - Measure Temperature
  - Produce and Store Power
  - Receive Power
  - Condition & Control Power
  - Collect and Calibrate Data
  - Receive Commands
  - Control Attitude
  - Operate in Low-Earth Orbit

All of these requirements will be verified during various verification events

EyasSAT Requirements Verification Matrix

Excerpt...

REQUIREMENT	VERIFY METHOD (LEVEL)	EVENT(S)	SUCCESS CRITERIA
***3.1 System Characteristics*: EyasSAT System characteristics shall be as refined by the following:**	Inspection (SYSTEM)	System Acceptance Review	If verification of all characteristic requirements have been successfully completed.
3.1.1. System Definition: EyasSAT system major components shall include the following: (1) Structure & Integration Subsystem (SIS), (2) Electrical Power Subsystem (EPS) Module, (3) Integrated Housekeeping data Unit (IHU) Module, (4) Communication Module (Comm), and (5) Attitude Determination & Control Subsystem (ADCS) Module, LED Test Module assembled as per specifications	Inspection (SYSTEM)	Subsystem Baseline Physical Inspections AND System Baseline Physical Inspection	If all specified major components are included
3.1.2. System Mass: Total system mass shall not exceed 3.0 kg, Subsystem mass is allocated as follows:	Inspection (SYSTEM)	System Baseline Physical Inspection	If system mass does not exceed 3.0 kg.
3.1.2.1 SIS Mass: SIS mass shall not exceed 1.5 kg.	Inspection (SUBSYSTEM)	Subsystem Baseline Physical Inspections	If SIS mass does not exceed 1.5 kg
3.1.2.2 EPS Mass: EPS Module mass, including LED Test Module, shall not exceed 0.5 kg.	Inspection (SUBSYSTEM)	Subsystem Baseline Physical Inspections	If EPS mass does not exceed 0.5 kg
3.1.2.3 IHU Mass: IHU module mass shall not exceed 0.25 kg	Inspection (SUBSYSTEM)	Subsystem Baseline Physical Inspections	If IHU mass does not exceed 0.25 kg

Example Verification Compliance Matrix

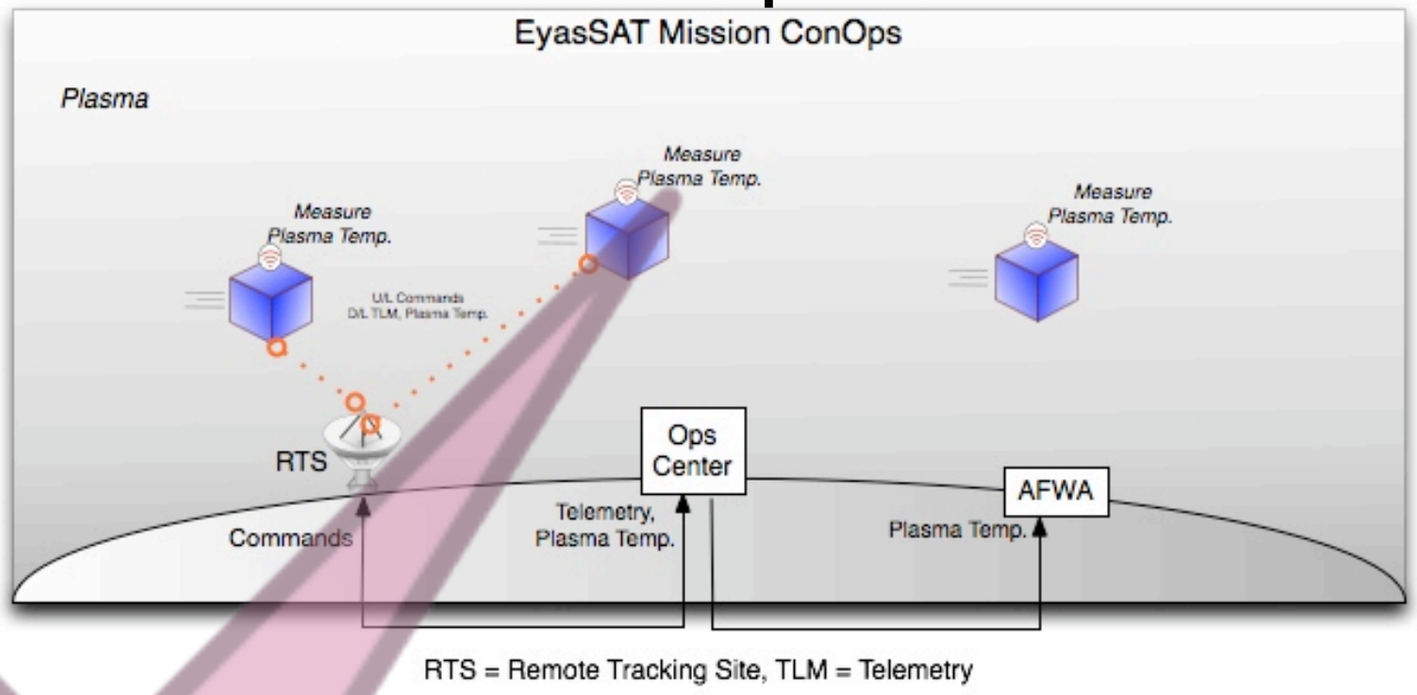
Event	Requirement(s) to be Verified	Success Criteria	Status (Pass/ Fail)
1.2.1.2. Software Verification Testing	**3.2.9.1. Call Sign Setting:** System call sign shall be configurable by operator between the values of 0 to 9	If call sign can be operator configured to values between 0 and 9	
	3.2.9.2. TLM Time Tag Setting: System telemetry time tag shall be configurable by operator over a 24 hour clock	If telemetry time tag can be operator configured to time on 24 hour clock	
	3.2.9.3. TLM Delay Setting: System telemetry delay shall be configurable by operator between 1 and 10 seconds	If telemetry delay can be operator configured to between 1 and 10 seconds	
	3.3.7. Calibrate Data: System shall calibrate payload and telemetry data for download in SI engineering units within +/- 10% of true values	If calibrated telemetry values equal independently measured values +/- 10 %	

Example: System Validation

Stakeholder Expectations

- KPP 1: Modular, nano-satellite less than 3 kg in mass
- KPP 2: Interface to existing small ground stations
- KPP 3: Provide multi-point (>5) space plasma temperature measurements to within +/- 3 deg of true ambient
- KPP 4: During a typical operational pass, no more than 3 operators shall be able to commission the system and record payload data

ConOps



Software Validation

Validation Events

“Test Like You Fly” Scrimmage

Conclusions

- EyasSAT enables a unique approach to space systems engineering training and education
- Student feedback overwhelmingly positive:
  - "Seeing the EyasSAT really helped me understand satellite systems. Addressed the reality/conflict between real-world hardware and pristine theory." –NASA/GRC Engineer
    "The hands-on experience made you think/remember that you often need to write test procedures for someone not familiar with your hardware." –NASA/GRC Engineer
    "It was a very good learning exerperience to see verification matrices and actual hardware IN THE SAME ROOM."—ESA Engineer
    "Great Course!" –Boeing Test Engineer
- For more information on EyasSAT courses
  - www.tsti.net
- For more information on EyasSAT hardware or to purchase
  - www.eyassat.com