OPTEC:
A Cubesat for Solar Cell Calibration

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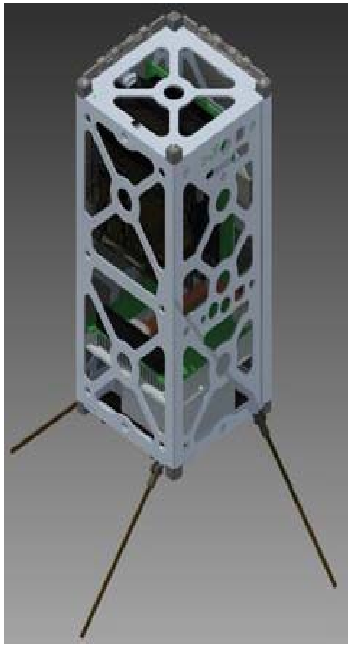
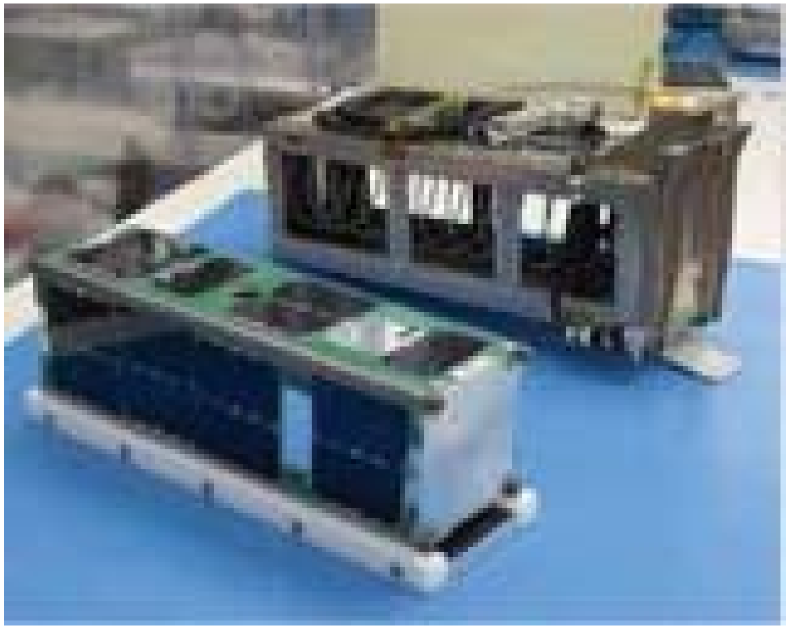


The Cubesat Revolution

Cubesats:

- **Tiny**: one unit (or “U” is 10 cm by 10 cm by 10 cm (four inch cube)
  - Standardized planform
  - Cubesats can be a single unit, 2-U, 3-U
  - < 1.3 kg per U
- **Cheap**
  - Launch as secondary payload on other missions
  - Often built as student projects
- Minimum function

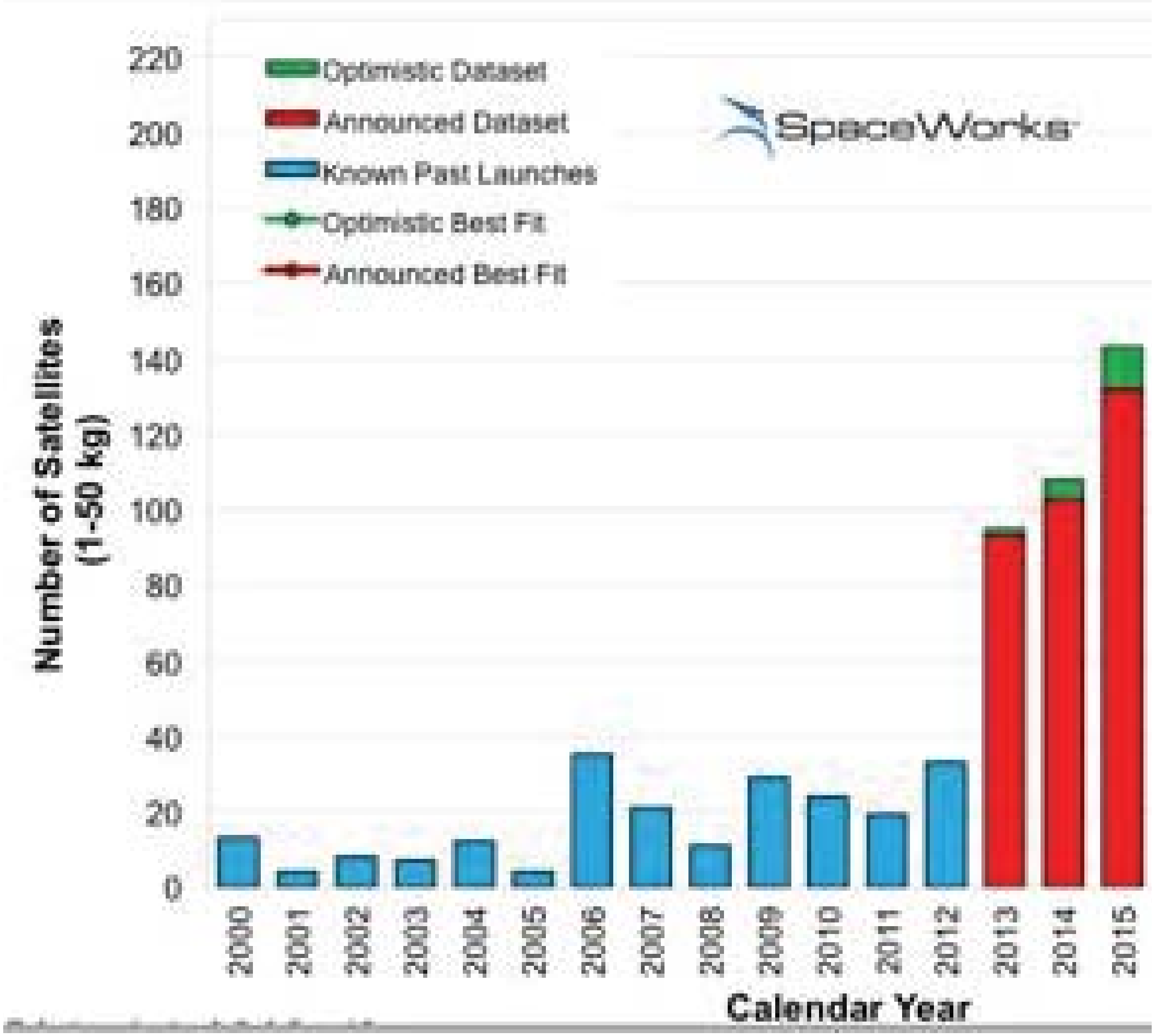
One-U cubesat



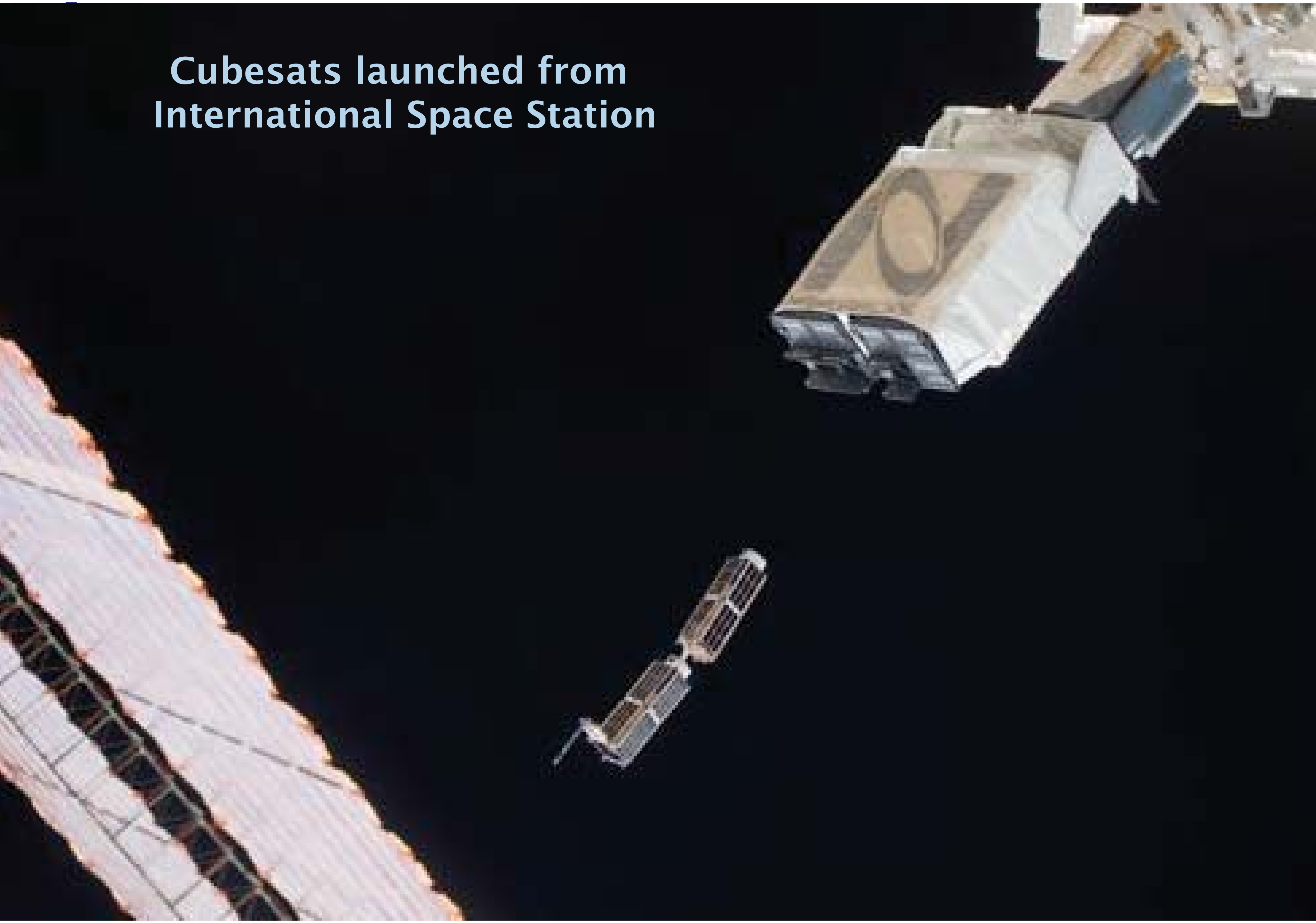
three-U cubesats

Cubesats

- Exponential Growth!



Data from http://www.sei.aero/eng/papers/uploads/archive/SpaceWorks_NanoMicrosat_Market_Feb2013.pdf


Cubesats launched from
International Space Station

Objectives

Background:

Current methods of testing new photovoltaic cells in the space environment are prohibitively expensive. In order to encourage innovation, low-cost, more accessible systems for testing are required.

Project:

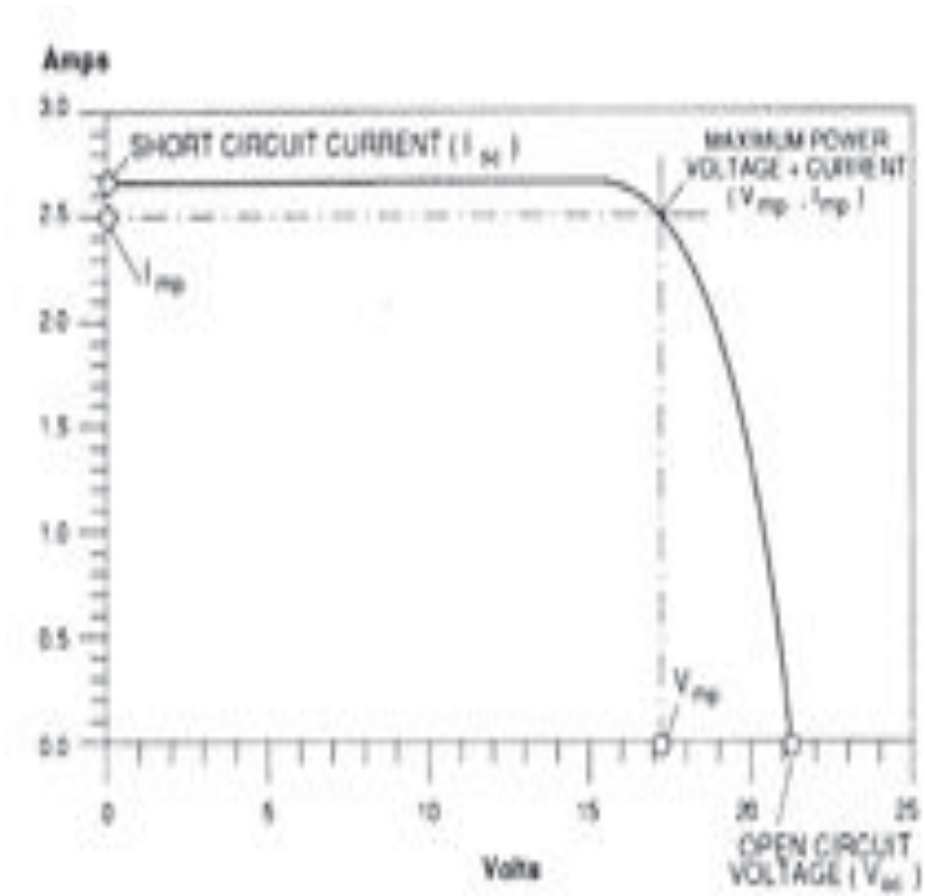
Conceptually design and prototype a low-cost, small satellite for LEO, which will be used to validate the function of new photovoltaic cell technologies in space by calibrating and measuring their performance.

Orbital Photovoltaic Testbed Cubesat (OPTEC) Specifications

- Size: 2U (10x10x20cm)
- Mass: 2.66 kg
- Launch: ISS Poly Picosatellite Orbital Deployer (P-POD) Launcher; systems power on 45 min after deployment per Cubesat requirements
- Initial Orbit (approx): 51° inclination, 420 km altitude (ISS orbit)
- Must transmit experimental data to ground station while in orbit

Payload

- The main purpose of the mission is to test solar cells and obtain I-V curves in LEO
- Two 4x8cm test solar panels will be attached to the top of the cubesat
- Use flight tested RRM PCB as main experiment board
  - 4 inputs: 2 test cells, 2 temp sensors
  - Test board triggered by main computer and sun sensor
  - The RRM PCB already qualified for flight. Initial launch would be flying the ground test board.
  - It is based on a design which we have flown 25 times in LEO for over 400 on-orbit processor-months.
- Test board will trigger when the satellite is within 8° of direct sunlight (>99% intensity)



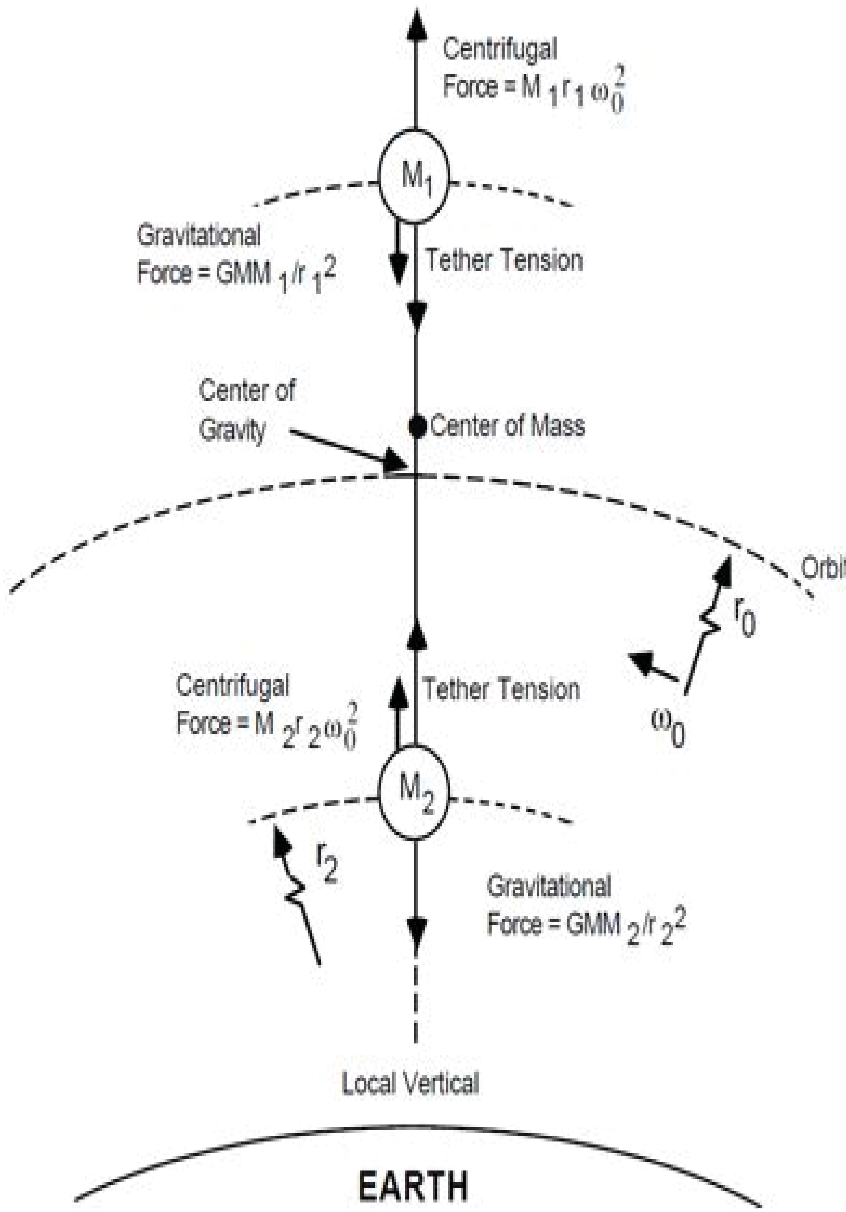
Example IV Curve

Attitude and Pointing

- **Spinning**
  - Satellite spin axis at a fixed direction in inertial space
    - Satellite orbits the Earth: axis not fixed relative to the Earth
    - Earth orbits around the sun: axis not fixed to the sun
    - Difficult to change pointing
  - How do we give the cubesat its initial spin?
    - Conservation of angular momentum
    - Must chose spin axis
- **Gravity gradient**
  - Axis of satellite aligned radially to the Earth
  - Passive: once in gravity gradient orientation, needs no control
  - How do we sun point?
    - At space station inclination, orbital plane precesses ~2 months
- **Three-axis control**
  - How do we control attitude?
    - Jets, reaction wheels, magnetic torque
  - Most complicated control

Gravity-Gradient Tether

- Completely passive alternative for station-keeping once in correct orientation
  - $F_{GG}=3Lmg/R_e$
- 5-6 m tether
  - tension ~10^-5 N
  - Invisible-thread like material
- Deployed only after initial detumble
  - Could theoretically completely replace Pointing controller
  - More detailed dynamics analysis/ simulation needed

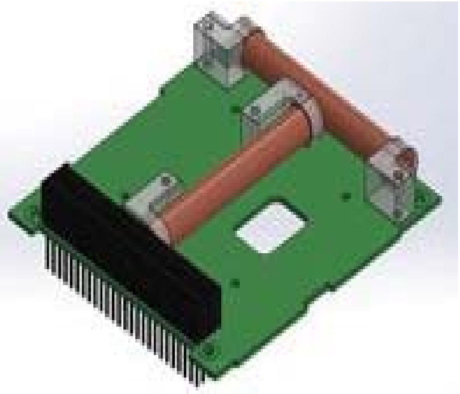


Attitude Determination and Control: detumble

- Deployment may give the satellite an initial rotation ("tumble")
- Rotation axis not specified
- Conservation of angular momentum: must transfer satellite's angular momentum somewhere
- Design requires cubesat to be stabilized in a specific radial orientation
- System: 3-axis Magnetorquers as primary control

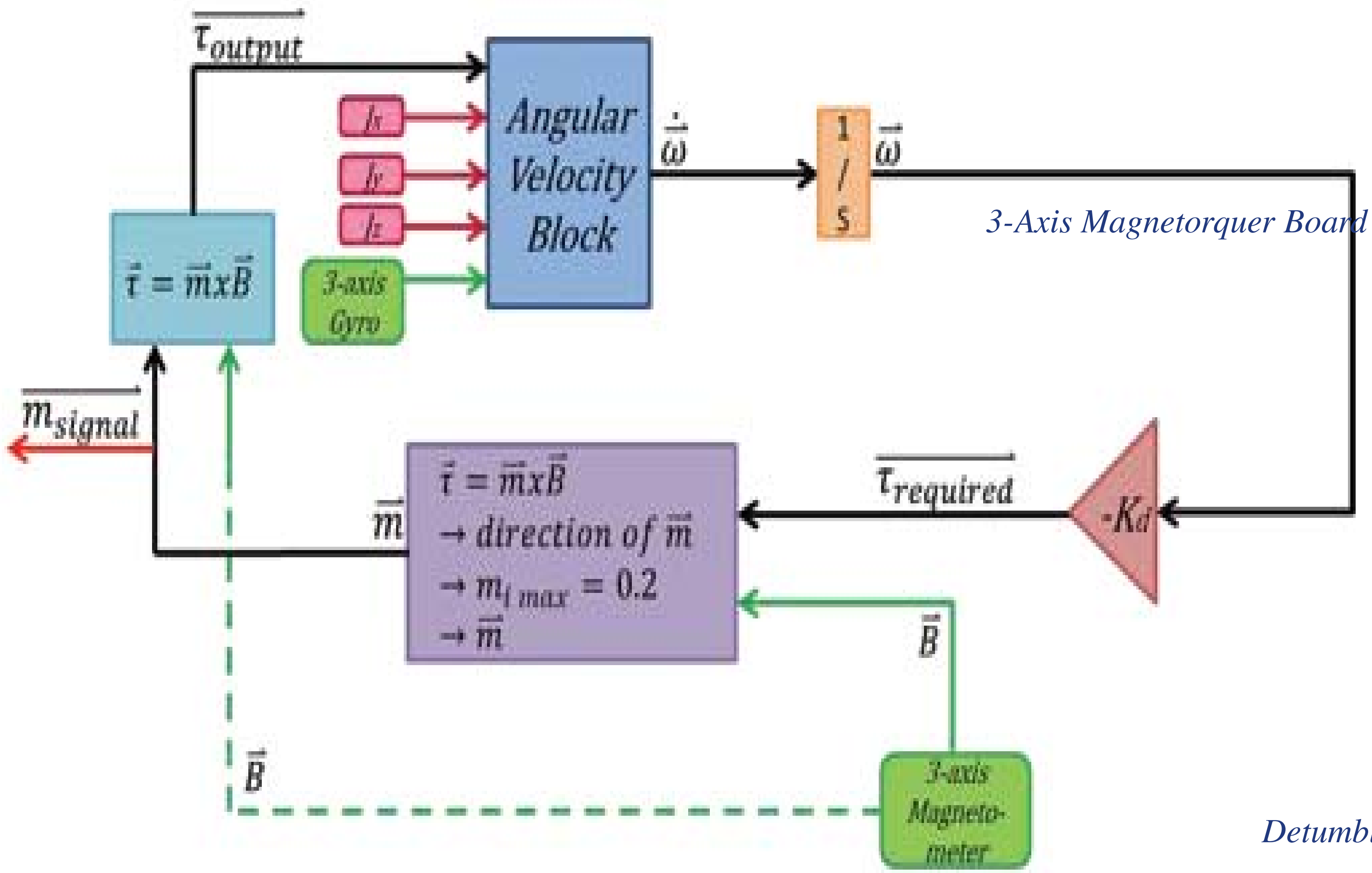
$$\vec{\tau} = \vec{m} \, x \, \vec{B}$$

  - Light, relatively cheap, low power
- Inputs: 3-axis magnetometers, gyros, and accelerometers; sun sensor
- Outputs: Current through magnetorquers



3-Axis Magnetorquer Board

Detumbling Control

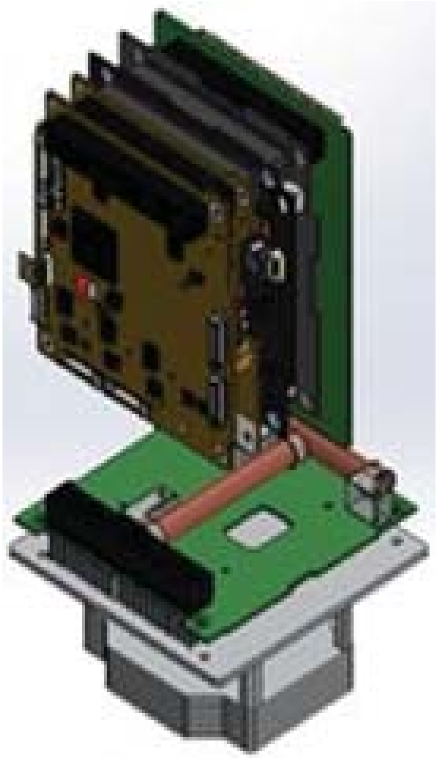


3-Axis Magnetorquer Board

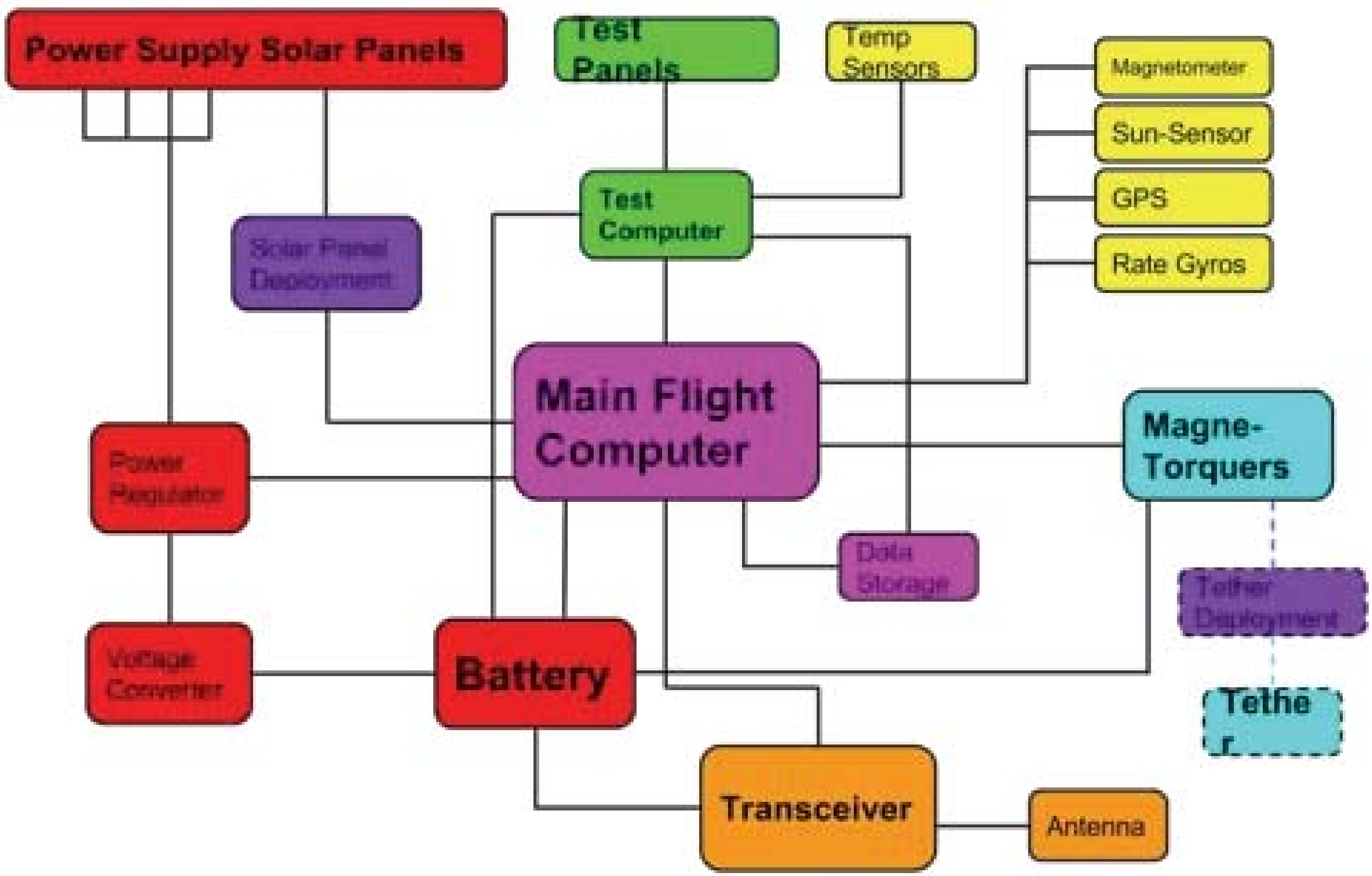
Detumbling Controller

Design Overview

- **Attitude Determination and Control**
  - Need to point test cells directly at sun→stabalize satellite in specific radial orientation
  - 3-axis magnetorquer control for detumble and pointing
  - Gravity gradient tether for passive radial stabalization & station-keeping
- **Payload**
  - 2 test solar panels
  - Obtain IV curves using flight tested RRM PCB triggered by sun sensor
    - 99% solar intensity = ±8° of sun
- **C&DH**
  - Main flight computer in charge of all satellite operations including deployments, ADCS, and test trigger
  - Radiation hardened components
- **Communications**
  - UHF or VHF radio band
  - Encode & compress data for transmission to ground station
- **Power**
  - 4 solar panels deployed at 45° charge Li-ion battery
  - Take into account eclipse time and angle to sun
- **Structure**
  - Pumpkin 2U Skeletonized Chassis
  - Vertically aligned boards in top U to accommodate test board
  - Counterweight is deployed from the bottom to create gravity-gradient
  - Deployable solar panels and antenna



Satellite Block diagram

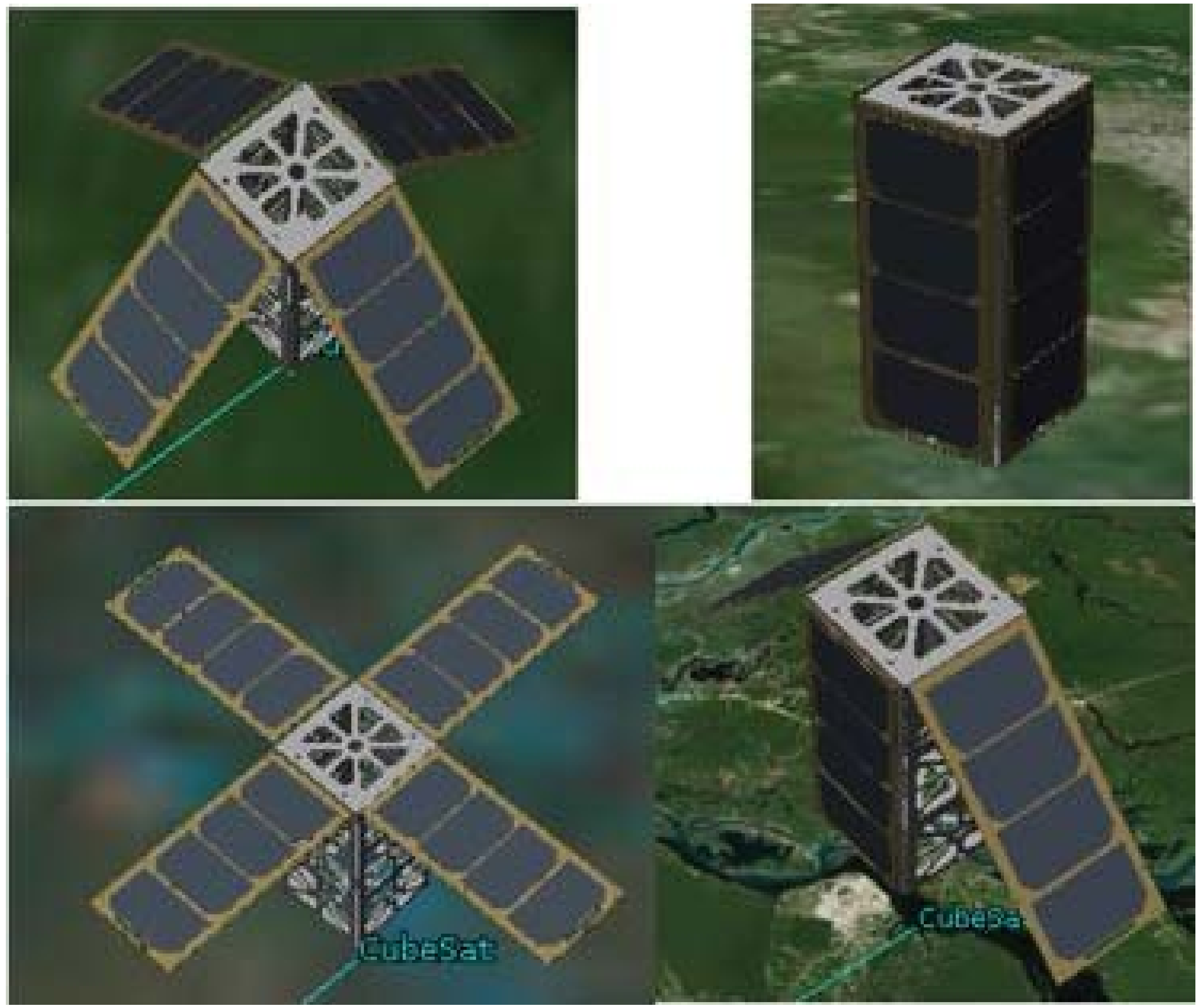


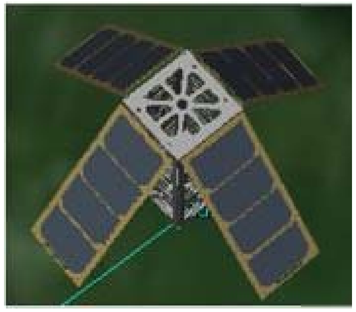
Power Design

- Supply power for cubesat operations
- Must take eclipse time into account
  - Need to regulate voltage and current to all components
- Source - 4 deployable solar panels
- Storage - Rechargeable Li-Ion battery
- Distribution - Modified off-the-shelf Electrical Power Systems (EPS) board
- Maximum power: 10.5 watts
- Average power: 3.5 watts

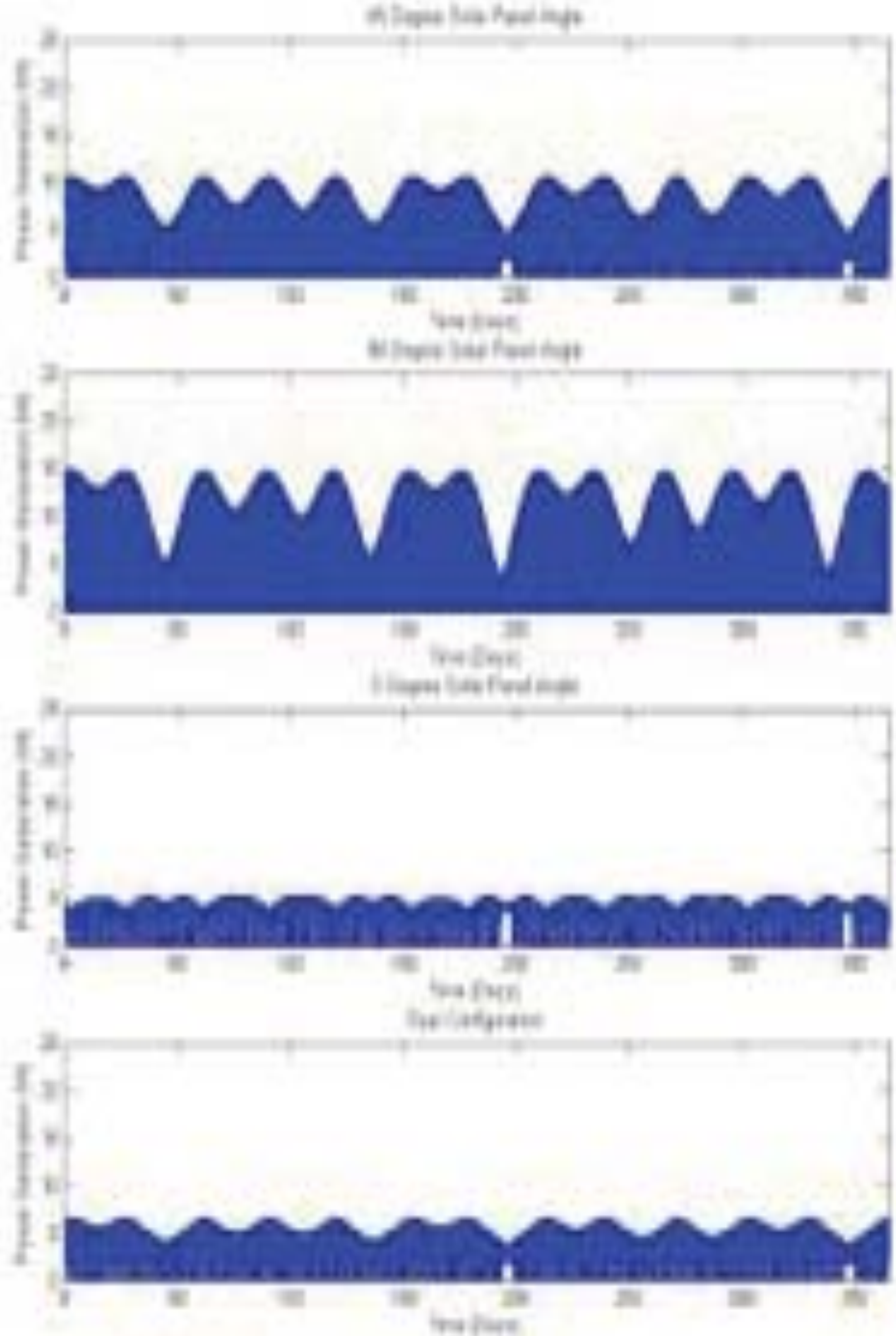
Power

Solar array designs analyzed:
(a) 45-degree deployment,
(b) body mounted, no deployment,
(c) 90-degree deployment,
(d) dual- body mounted 45-degree deployment.

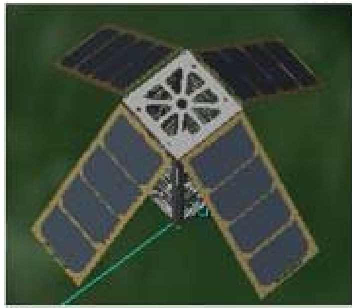


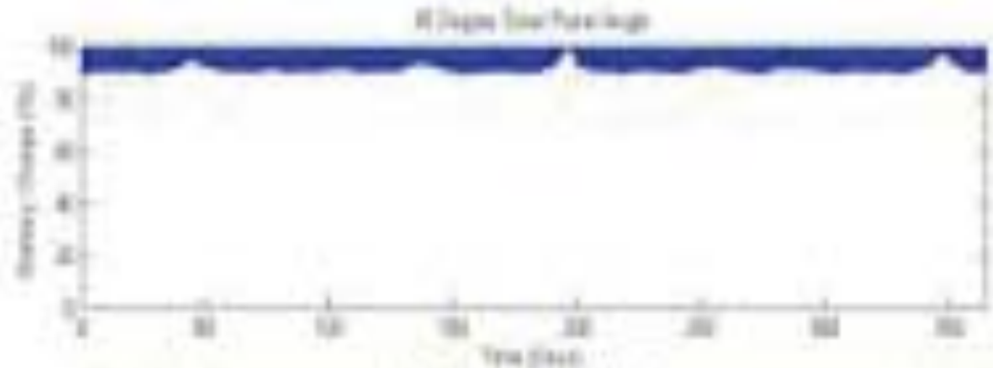


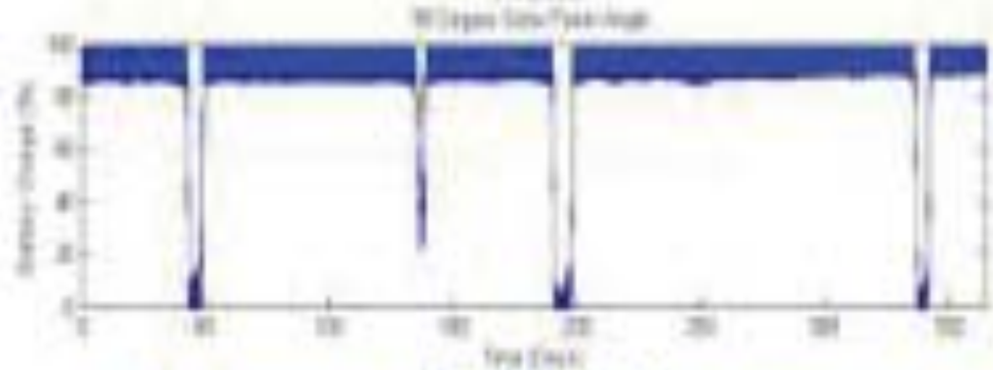
Power Generation

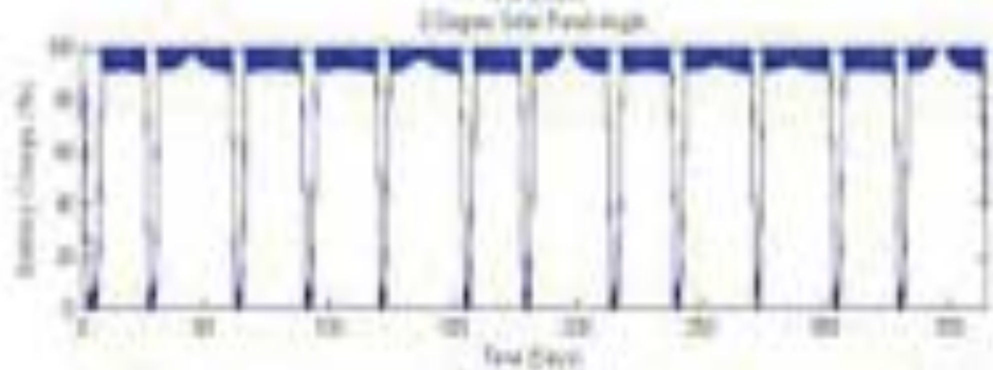


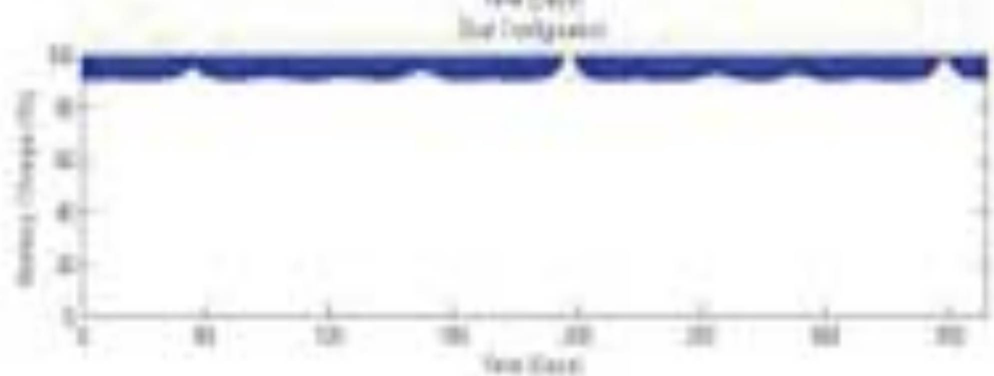
Battery State of Charge



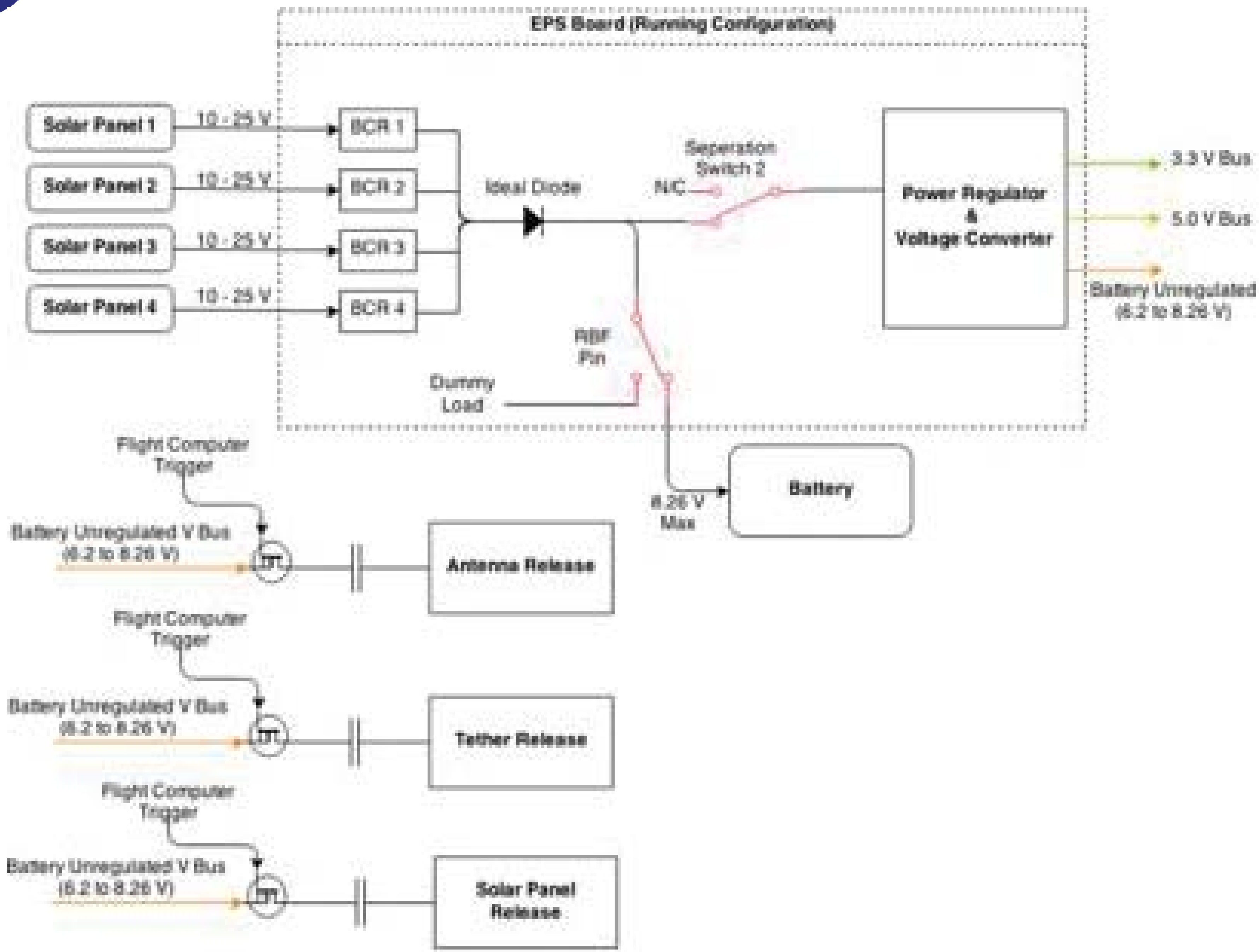








Power block diagram



C&DH and Communications

- Need main fight computer to carry out satellite functions autonomously
  - Inputs - sensors, experimental data, ground commands
  - Outputs - ADCS commands, triggers (deployment / experiment)
  - Encode / compress data to be transmitted to ground
    - Error checking / correction
  - Radiation hardened components
- Need to transmit experimental data and images to ground station
  - UHF or VHF amateur radio bands easiest to work with
- Transmission time will be ~5 min at least once a day

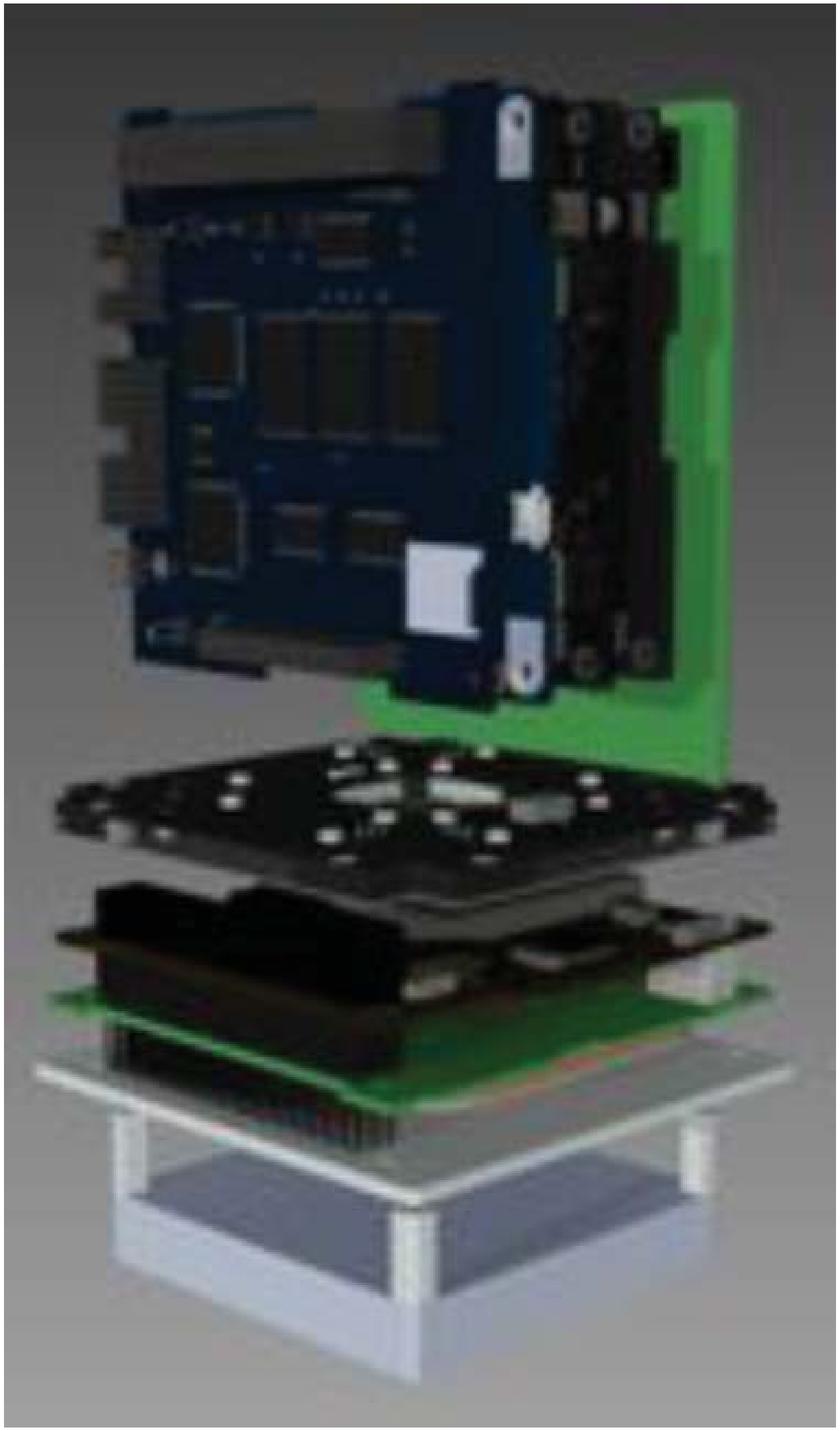
Communications

- Strawman board: based on Pcsat-2
  - Space Station amateur radio experiment
- 100 gram transmit board
  - 2-watt UHF transmitter
- 110 gram receive board
  - VHF receiver
- Transmission time will be ~5 min at least once a day

- This is not the final com design: Need to do trade study: will look into use of commercial com board

Interior configuration

- How the interior boards fit inside the 20 x 20 x 20 cm form



Components

Mass and Cost Budget

COMPONENT	MASS (g)	COST ($)
Attitude Determination & Control System		
3-axis magnetorquer	200.00	10,215.00
GPS	106.00	7,980.00
Tether	20.00	10.00
Tether Counterweight	100.00	15.00
Deployment Springs	10.00	10.00
Payload		
RRM PCB (test board)	100.00	0.00
Temperature Sensors	10.00	20.00
Sun Sensor	25.00	6,000.00
3-axis magnetometer	2.00	30.00
3-axis gyro	2.00	30.00
3-axis accelerometer	2.00	30.00
Cameras	5.00	30.00
Thermal		
Paint	20.00	100.00

COMPONENT	MASS (g)	COST ($)
Structure		
Frame	217.00	1,625.00
Rod/spacers	75.00	225.00
Power		
Deployable Solar Panels	540.00	21,800.00
EPS	133.00	9,450.00
Battery	85.33	1,800.00
Comms		
Transceiver	85.00	11,500.00
Antenna	50.00	6,000.00
C&DH		
Main board	50.00	6,000.00
Misc. cables, wiring,etc.	450.00	1,000.00
RAW TOTAL	2,287.33	83,870.00
15% growth	343.10	12,580.50
TOTAL	2,630.43	96,450.50

High-Altitude Balloon Launch

- Opportunity to test prototype systems in a low cost way
  - Primary test of electronic and sensor systems as well as tether deployment
- Validate system design in a near space environment
- Payload fabricated with parts already purchased

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