ParkinsonSAT

CDR Bruninga
USN (ret)

David Koeppel
Matt Lovick
James Paquette
Brian Piggrem
Jeff Robeson
Kyle Vandegriff

72% Aloha
144% Slotted
CR = 4 x AR

Lovick
ParkinsonSAT

- $50k gift funds from Aerospace Corp.
- Environmental sensor satellite data transponder
- Satellite Launch Opportunities - TBD
- This semester, Preliminary Design options --> SRR
Original Project Proposal

- Communicate with simple environmental sensors – buoys – deployed in the Chesapeake Bay or the Gulf Stream.

- Relay buoy position/status and telemetry about 2 to 4 times a day back to the Naval Academy.

- Including Buoys elsewhere around the world as long as an internet linked ground station was in the footprint.

- Serve as a technology demonstrator for USNA auxiliary payloads such as basic satellite attitude control.
Proposed Mission

- **Relay data from simple environmental sensors** – buoys – in the Chesapeake Bay or oceans or onshore. Providing position/status and telemetry about 2 to 4 times a day to the Internet.

- Including Buoys elsewhere around the world as long as Internet linked ground stations are in the footprint.

- **Establish this channel/system as a global resource** for other such experiments in the Amateur Satellite Service. Inspire other schools and universities to participate with additional low cost satellite transponders and buoy and sensor systems.

- Serve as a technology demonstrator for various spacecraft subsystems including basic attitude control, follow-ons to PCSAT experiments and other student projects such as the MIDN sensor.

- **Support an Ocean Data Telemetry Microsat Link (ODTML) UHF transponder for DOD.**
Low Cost Buoy System

- Low Cost ~ $800
- Standard plumbing hardware
- Off-the-shelf radios/modems
- Operates under FCC rules for Amateur Satellite Service
Global Ground Station Network

Needs only a Radio, Modem, PC and Internet

And PCSAT2

ISS / PCSat Internet Linked volunteer Groundstations
Micro Dosimeter (MIDN) Requirements

Auxiliary USNA Aerospace Student Project Payload

- Size – 2.5” x 2.5” x 6”
- Weight – .215 kg
- Power – 1W (@ 5v)

Measures radiation dosage in human cell sized detectors
CONOPS: “Internet-Like” Services on Global Basis to Support Ocean Platform Monitoring (e.g., Free-Floating Buoys)

SPACE SEGMENT:
- Hosted Aboard TacSat-3 and TacSat-4
- Autonomous “Router in the Sky” Allows User Commanding and Telemetry Receipt (Peer-to-Peer and Store/Forward)
- Compatible With Service ARGOS; >50,000 Bits/Day per Buoy; <0.1 Joule/Bit With Global Access and Position Determination
- UHF Uplink/Downlink With GMSK Modulation

GROUND SEGMENT: Low-Cost Portable and Fixed Ground Stations Provide Virtual Internet Access

ODTML PAYLOAD: SCP
- Multiple UHF Frequencies
- FPGA Controller

ODTML SPACE SEGMENT

TacSat-4 BUS

Standby” CMD
Temperature
Power

UHF XCVR
FPGA
Memory

Vandegriff
ONR ODTML

Size, Weight and Power

- **Size** – 10” X 10” X 1.8”
- **Weight** – 3.7 kg
- **Power**

<table>
<thead>
<tr>
<th>Power Level</th>
<th>Value</th>
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<tbody>
<tr>
<td>Peak (Watts)</td>
<td>40</td>
</tr>
<tr>
<td>Nominal (Watts)</td>
<td>9.5</td>
</tr>
<tr>
<td>Average (Watts)</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Very conservative numbers, and massive design.

Vandegriff
Project Variables

- Requirement Options?
- Launch Options?
- Scale options?
- Resource Limitations?
ParkinsonSAT
Spiral Design Approach

REQUIREMENT OPTIONS:
- Remote Data Relay (ocean)
- Environmental Sensors (land)
- Secondary Payloads
  - MIDN
  - Attitude Control
  - Comms Power levels

RESOURCE LIMITS:
- Risk
- Materials
- Flexibility
- Lead times
- Cost / Funding
- Semester Timing

FLIGHT OPTIONS:
- SERB feedback
- Launch opportunities
- Orbits Available
- Link Budgets
- Flight Schedule

SCALE OPTIONS:
- Number of Satellites
- Number of Buoys/Sensors
- Number of Participating Schools
- Global Coverage Areas
- Buoy Power Budget
**ParkinsonSAT**

**Link Budget is Known**

- **Buoy to Satellite (VHF)**
  - $Pr (90° \text{ el}) = -101 \text{ dBm}$
  - $Pr (0° \text{ el}) = -117 \text{ dBm}$

- **Satellite to Buoy (UHF)**
  - $Pr (90° \text{ el}) = -110 \text{ dBm}$
  - $Pr (20° \text{ el}) = -117 \text{ dBm}$
  - Satellite to Buoy (VHF) aux TX
  - $Pr (90° \text{ el}) = -101 \text{ dBm}$
  - $Pr (0° \text{ el}) = -117 \text{ dBm}$

- **Satellite to Groundstation (UHF)**
  - $Pr (90° \text{ el}) = -110 \text{ dBm}$
  - $Pr (20° \text{ el}) = -117 \text{ dBm}$

- **Satellite to Trackingstation (UHF) +8 dB**
  - $Pr (90° \text{ el}) = -102 \text{ dBm}$
  - $Pr (0° \text{ el}) = -117 \text{ dBm}$

**Challenge:** All using OMNI antennas

RX sensitivity $-117 \text{ dBm}$

Vandegrieff
Sensor Buoy Baseline

PCSAT validates our links

PCSAT2 User Plot 18 Apr 06
Sensor Buoy Baseline

GOES data collection platform container

Our RF prototype on Roof

Paquette, Robeson
Sensor Buoy Baseline

Number of Buoy Packets Received Per Day via PCSAT-1 and PCSAT2

March 2006

- Telemetry
- Position
- Beacon

PCSAT-1 shuts down due to negative power budget

- gnd stn was off
- crew activity on voice during most passes, jams uplink
- PC2 shut down 18 hrs for Soyuz docking
- PC2 jammed by school contact
- PC2 uplink jammed by school contact
- crew activity on voice during most passes, jams uplink
- PSK experiments on PC2 most passes

Paquette
Launch Opportunities

- **Free Flyer** (comms orbit) - Desired

- **Attached Payload** – OK

- **Space Shuttle** – too low, no life...
  - Available Launcher – 5” picosat (minimum system)
  - Requires a Propulsion system (H$_2$O$_2$ man-safe)
H$_2$/O$_2$ Man Safe Propulsion

The only practical way to get a student built propulsion system on board Space Shuttle. Inherently SAFE.

Possible Future Project:

Project:
- Determine spacecraft mass then delta-V requirement
- Electrolysis requirements, rates, power required
- Valve availability and drive requirements
- Water/gas separation mechanism (gortex?)
- Design-Build-Test engineering model
- Final conceptual design
Mission Scale - Channel Capacity

- Time Division Multiple Access (TDMA)
  - Pure ALOHA 18% channel capacity
  - CSMA ALOHA 36% channel capacity (not via sat)
  - Slotted ALOHA 36% (uses GPS timing)

Lovick
Mission Scale - Receivers

Channel Rate = TDMA Aloha Rate

Full-duplex, Crossband

Simplex / In-band

Lovick
Mission Scale – Options

Minimum System:
- 32 Buoys/footprint
- 5” Picosat

Maximum system:
- 144 Buoys/footprint
- Dual redundant
- 12” Microsat

AT 1200 BAUD
(2 x if 2 RX at 9600)
Mission Scale – Buoy Demographics

Global coverage for 3000 km radius footprints. One footprint is about 5% of area. Overall global average duty cycle is about 20%.

Theoretical capacity: 2880
144/5%

Expected capacity: 720
144/20%

Lovick
Architecture

ParkinsonSAT Functional Block Diagram

Vandegriif
Small Satellite Structural Options

- Primary factor is solar panel sizing
- Next is Antenna requirements
- Separation System
- Attitude Control requirements
Solar Panel Options

- Available Area
- Efficiency
- Cost
- Attitude
- Bus Voltage
Solar Cell Options

PCsat Panel

$20 / Watt

EMCOR University Cells

$500 / Watt

15%

23%

Koeppel
PCSat Solar Panel Data

5 year degradation 35%
Emcor University Cell Options

4 cell 8V set

6 cell 12V set
ParkinsonSAT
Shape / size Constraints

- 5 in Cube
- 7 in Cube
- 9 in Cube
- Rhombicuboctahedron
- Hexagonal
- Vandegriff
## ParkinsonSAT

### Shape / Size Constraints

<table>
<thead>
<tr>
<th>Shape</th>
<th>Solar Panels</th>
<th>Max Power (W)</th>
<th>Min Power (W)</th>
<th>Volume (in^3)</th>
<th>Surface Area (in^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5in Cube</td>
<td>6</td>
<td>3.49</td>
<td>2.03</td>
<td><strong>125</strong></td>
<td>150</td>
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<tr>
<td>7in Cube</td>
<td>12</td>
<td>7.04</td>
<td>4.06</td>
<td><strong>343</strong></td>
<td>294</td>
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<tr>
<td>9in Cube</td>
<td>24</td>
<td>14.1</td>
<td>8.13</td>
<td><strong>729</strong></td>
<td>486</td>
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<tr>
<td>Hexagonal</td>
<td>9</td>
<td>6.10</td>
<td><strong>1.67</strong></td>
<td>208.8</td>
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<tr>
<td>Octagonal</td>
<td>12</td>
<td>8.13</td>
<td>2.45</td>
<td>273.5</td>
<td>314</td>
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<tr>
<td>Rombicuboctahedron</td>
<td>18</td>
<td>9.15</td>
<td>7.78</td>
<td><strong>1061</strong></td>
<td><strong>518</strong></td>
</tr>
</tbody>
</table>

Vandegriff
**Parkinson SAT**

**Straw-man Options**

**5" DOD Picosat Option**
- 1.5 Watts per side
- Total Panel cost $150

**6" High Efficiency Option**
- 6 Watts
- Total Panel Cost $18,000

**7.5" Best Fit (minimum) Internals**
- 3 Watts per side
- Solar Panel Cost $300

Discrete sizes

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ParkinsonSAT

Sun Pointing

Straw-man Designs

10" Option with 12 volt Bus

10 Watts $5000 × 6 = $30,000

Side View 6W $100
12" Full Size (maximum) Option
18 Watt $9,000

12" Side Panel
8.4 volts, 900 mA, 75 Watts
ParkinsonSAT
Sun Pointing Design

- Full capacity mission transponders
- ODTML Transponder
- MIDN Payload
- ADCS advantage
ParkinsonSAT
Internal Stack

- Full capacity mission transponders
- ODTML Transponder
- MIDN Payload
- ADCS advantage
Parkinson SAT

TX-RX Tray

- 2 VHF receivers
- 1 or 2 XMTRS
- MIDN Payload
- Support Boards

Koeppel
TX-RX Tray

Representative Tray Designs

Layout favors +Z maximum moment of inertia

TNC / Battery Tray

Koeppel
Sun Pointing Attitude Control System

- Reduces solar panel cost, $54,000 to $9000.
- Pointing requirements are relaxed +/- 40 deg
- Attitude sensing via solar currents is sufficient
- Table derived magnetic field data
- High precision vector math not required
Sun Pointing Attitude Control System

- Pointing requirements are relaxed ±40 deg
- High precision vector math not required
Magnetic Field Vector

Prof Ingle, Physics

76 deg W
Worst Case Disturbance Torques:

- **Gravity Gradient** (~balanced MOI from RAFT model)
  \[ T_g = \frac{3\mu}{(2r^3)|I_z - I_y|}\sin(2\theta) \]
  \[ T_g = 6.30 \times 10^{-25} \text{ N-m} \approx 0 \text{ N-m} \]

- **Solar Radiation**
  \[ T_{sp} = F(C_{ps} - C_g) \text{ w/ } F = \frac{F_s}{C_s A_s (1+q) \cos(i)} \]
  \[ T_{sp} = 1.03 \times 10^{-7} \text{ N-m} \]

- **Aerodynamic Drag** (Assumed 500 km)
  \[ T_a = \frac{1}{2} \rho C_D A V^2 (C_{pa} - C_g) \]
  \[ T_a = 1.48 \times 10^{-6} \text{ N-m} \]

- **Total Disturbance Torque**
  \[ T_d = 1.58 \times 10^{-6} \text{ N-m} \]

Dipole Needed to Cancel Torques (weakest Earth field at 500 km):

- \[ D = \frac{T_d}{B} \text{ w/ } B = 0.31 \times 10^{-4} \text{ T} \]
  \[ D = 0.051 \text{ A-m}^2 \]
Magnetic Torque Coils

**Torque Lab Experiment**
- 200 turns #30
- 42 Ohms, 200 mA
- 1.3 Amp * M^2
- 1.4 kg
- Results in 5 deg / sec

**Suggests for ParkinsonSAT**
- 200 turns #30
- 4 Amp * M^2
- 14 kg
- Results in 1.5 deg / sec

Using 10% dutycycle pulsing still gives 10 dB margin
## Preliminary Mass Budget

<table>
<thead>
<tr>
<th>Part</th>
<th>Mass (g)</th>
<th>Quantity</th>
<th>Total (g)</th>
</tr>
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<tbody>
<tr>
<td><strong>Structure</strong></td>
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</tr>
<tr>
<td>Side Panel</td>
<td>696</td>
<td>4</td>
<td>2787</td>
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<tr>
<td>PCSAT Solar Panel</td>
<td>77</td>
<td>25</td>
<td>1940</td>
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<tr>
<td>Top/Bottom Panel</td>
<td>796</td>
<td>2</td>
<td>1592</td>
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<tr>
<td>EMCOR Solar Panel</td>
<td>24</td>
<td>24</td>
<td>57</td>
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<tr>
<td>Mounting Tray</td>
<td>669</td>
<td>6</td>
<td>4015</td>
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<tr>
<td>Battery Box</td>
<td>354</td>
<td>1</td>
<td>354</td>
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<tr>
<td><strong>Comms</strong></td>
<td></td>
<td></td>
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<tr>
<td>VHF RX</td>
<td>78</td>
<td>4</td>
<td>313</td>
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<td>Linear RX</td>
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<td>VHF TX</td>
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<td>UHF TX</td>
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<td>Voice Module</td>
<td>10</td>
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<td>10</td>
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<td>TNC</td>
<td>204</td>
<td>2</td>
<td>409</td>
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## Preliminary Mass Budget (cont)

<table>
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<th>Payloads</th>
<th>Mass (g)</th>
<th>Quantity</th>
<th>Total (g)</th>
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<tr>
<td>MiDn</td>
<td>529</td>
<td>1</td>
<td>529</td>
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<tr>
<td>ODTML Transponder</td>
<td>3700</td>
<td>1</td>
<td>3700</td>
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<tr>
<td><strong>ADCS</strong></td>
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<tr>
<td>x-coil</td>
<td>127</td>
<td>1</td>
<td>127</td>
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<tr>
<td>y-coil</td>
<td>127</td>
<td>1</td>
<td>127</td>
</tr>
<tr>
<td>z-coil</td>
<td>110</td>
<td>1</td>
<td>110</td>
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<tr>
<td>CPU</td>
<td>62</td>
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<td>62</td>
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<tr>
<td><strong>Power</strong></td>
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<tr>
<td>Battery</td>
<td>23</td>
<td>36</td>
<td>856</td>
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<tr>
<td><strong>Overall Total</strong></td>
<td></td>
<td></td>
<td>17.3 kg</td>
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# Preliminary Required Power Budget

<table>
<thead>
<tr>
<th>Description</th>
<th>Current (mA)</th>
<th>Duty Cycle</th>
<th>Avg (mA)</th>
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</thead>
<tbody>
<tr>
<td><strong>4 RX / 2 TX</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VHF FM TX1</td>
<td>500</td>
<td>15%</td>
<td>75</td>
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<tr>
<td>VHF FM TX2</td>
<td>500</td>
<td>15%</td>
<td>75</td>
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<tr>
<td>VHF FM RX1</td>
<td>30</td>
<td>100%</td>
<td>30</td>
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<tr>
<td>VHF FM RX2</td>
<td>30</td>
<td>100%</td>
<td>30</td>
</tr>
<tr>
<td>VHF FM RX3</td>
<td>30</td>
<td>100%</td>
<td>30</td>
</tr>
<tr>
<td>VHF FM RX4</td>
<td>30</td>
<td>100%</td>
<td>30</td>
</tr>
<tr>
<td>TNC1</td>
<td>30</td>
<td>100%</td>
<td>40</td>
</tr>
<tr>
<td>TNC2</td>
<td>30</td>
<td>100%</td>
<td>40</td>
</tr>
<tr>
<td>W/o MiDn/ODTML</td>
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</tr>
<tr>
<td><strong>20% Reserve</strong></td>
<td>40</td>
<td></td>
<td>40</td>
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<tr>
<td>Avg (mA)</td>
<td>390</td>
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<table>
<thead>
<tr>
<th>Description</th>
<th>Current (mA)</th>
<th>Duty Cycle</th>
<th>Avg (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With MiDn only</td>
<td>119</td>
<td>100%</td>
<td>119</td>
</tr>
<tr>
<td><strong>20% Reserve</strong> (tot)</td>
<td>64</td>
<td></td>
<td>64</td>
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<tr>
<td>Avg (mA)</td>
<td>533</td>
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<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Current (mA)</th>
<th>Duty Cycle</th>
<th>Avg (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With MiDn and with ODTML transponder</td>
<td>1488</td>
<td>100%</td>
<td>1488</td>
</tr>
<tr>
<td><strong>20% Reserve</strong> (tot)</td>
<td>361</td>
<td></td>
<td>361</td>
</tr>
<tr>
<td>Avg (mA)</td>
<td>2318</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Vandegriff
For a typical COMM orbit at 500 miles, satellite will require 630 mAh. Based on 20% DoD this requires either 27 AA’s, 12 C’s or 7 D cell NiCads.

Dual Voltage Bus for best efficiency / simplicity
Launcher Separation Devices

Cubesat Launcher
SSDL5510 for 5" RAFT's

NEA

USNA Launch Vehicle Interface
(single Wedge configuration)
CPU Design

Adding CPU to basic PCSAT type design for:

- Collect and transmit whole orbit data telemetry
- Event scheduler
- Data logger
- Attitude control system
- Store and Forward

Includes…

- Serial port, 9600 or 1200 baud
- 8-bit parallel I/O
- 5 or more analog inputs

Development Board

CPU Module

Piggrem
Prototype Buoy Design

- **Design aspects similar to spacecraft:**
  - Power System (EPS) (low-power & efficiency)
  - Communications System (link budget)
  - Sensor system (collaborating with Oceanography)
  - Telemetry System
  - Antenna System (antenna patterns)

- **Structure**
  - Collaborating with Hydro Lab
Sensor Buoy Baseline

- Naval Academy Student Project
  * If free-floating, do not disturb.
  * If aground, move to deep water and advise bruninga@usna.edu
  * If later than 30 Nov 2006, recover and advise above.

Battery photo
## Buoy Power Budget

<table>
<thead>
<tr>
<th>Component</th>
<th>Voltage (V)</th>
<th>Resistance (Ω)</th>
<th>Current (mA)</th>
<th>Time On (h)</th>
<th>Capacity (mAh/day)</th>
<th>Battery Life (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energizer 6V Lantern Battery (No. 529)</td>
<td>6</td>
<td>110</td>
<td>54.55</td>
<td>2.4</td>
<td>130.91</td>
<td>26</td>
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<tr>
<td>Garmin GPS-18</td>
<td>110</td>
<td>2</td>
<td>220</td>
<td>88</td>
<td>128</td>
<td>26</td>
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<tr>
<td>Transmitter</td>
<td>500</td>
<td>0.2</td>
<td>100</td>
<td>40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 2 batteries required to get 12v BOL and 7v EOL

Piggrem, Koeppel
Prescribed Timing Requirements for Bay Mission

- GPS – 1.4 minutes on every 23.4 minutes
- Transmits every 10 minutes
- TNC – 11 seconds on every 11 minutes

Prescribed Timing Requirements for Ocean Mission

- TNC – 22 seconds on every 2.9 minutes
- GPS – 1.4 minutes every 46.9 minutes
- Transmits every 2.9 minutes
Buoy Logic Timing Hardware Integration

- Astable Operating 555 Timer (Clock Input)
- 54HC4040 12-Stage Binary Ripple Counter
- Triple 3-Input Positive Nand Gate Chip
- Quadruple 2-Input Positive Nand Gate Chip
10 Channel Telemetry Multiplexer for the KPC-3

- Battery Volts
- Air Temp
- Water Temp
- Sun luminosity
- Conductivity
- Flooding

Paquette
ParkinsonSAT Thermister Calibration Curve

Raft Temperature Data from Heat Chamber and Freezer

\[ y = 0.000012523x^2 - 0.004136641x^2 + 0.804651759x - 38.263489069 \]

\[ R^2 = 0.999493040 \]

Paquette
Buoy Antenna Design

Upper 1/2 Wave Element Section

39 and 1/2 inches

1/2 wave radiator

Lower Folded 1/2 Wave Matching Section

18 and 1/2 inches

1/4 wave matching section

short tuning section

50 Ohm coax

radio connector

70 %

Drum Curve of Buoy Antenna

O/H3 of Buoy Antenna
ParkinsonSAT
5” Option
microgravity
Separation Test

March 30th – April 8th
(“Test of Opportunity”)
Test 5” cubesat separation system
Questions?
- **PCSat2 Operations**
  - Daily Antenna Pointing
  - Low Power Shutdown
  - Soyuz Docking
  - EVA’s
    - SuitSAT deployment