Panel Extension Satellite (PETSAT)

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University of Tokyo’s Nano-Satellite Projects

- **2003:** CubeSat XI-IV ‘03/6
- **2004:** CubeSat XI-V ‘05/10 (Twin-Sat with XI-IV launched with SSETI-EXPRESS)
- **2005:** PRISM (Remote sensing) launch in ‘07
- **2006:** NANO-JASMINE (Astrometry Satellite) ’08-‘09
- **2007:** PRISM (Remote sensing) launch in ‘07
- **2008:** PETSAT (Panel Satellite) ’09-‘10

**Development** ➔ **Launch**
Applications:
- Solar Power Generation
- Large Antenna
- Debris Removal
- Large Radiator
- etc.

Concept of Furoshiki Satellite
Sounding Rocket Experiment 1/22/2006

Pilot Signal for retro-directive antenna

Antenna Pattern Measurement
Problems of Current Satellite Concepts

- Conventional Satellite
  - Development Period: 2 ~ 7 years
  - Development Cost: $20M ~ $500M

Because of “custom-made” style in order to deal with varied mission requirements.

Mass Production: Key to reduce cost and development time, and improve reliability

**Question:** How to satisfy the two conflicting requirements of “mass production” and “variety of performance”
Plug-in of Panels having different functions deal with variety of mission requirements just like a “Lego Block”

- Mass production of panels lead to low cost/high reliability
- Plug-in makes system level test simple and less time consuming
- Open architecture to allow participation of new companies with special tech.
- Extending panels makes it possible to use small satellite as “large sat”
(1) Architectural Study
Function Distribution into Panels

*How to distribute OBC, memory, attitude control, power, communication, etc, into (how many) different panels*

- Each panel has “Standard compo.” + “Special compo.”
  - Inter-panel communication controller is indispensable
  - How about solar cell, battery, CPU?
  - Inter-panel communication capacity should be considered
- Easy plug-in of any quantity of panels should be possible
  - Distributed architecture like “Personal Computer on Internet”
- Fault tolerance required including panel interface failure
  - Tolerant against electric or information line failure
  - Graceful degradation and reconfiguration capability
- Should deal with variety of mission requirements by changing types and quantity of panels
  - Ex) Two communication panels should have double capacity
Overall Architecture of Functional Panels

• **Types of Panels**:
  - ① OBC+memory  ② communication  ③ attitude control  ④ orbit control  ⑤ battery  ⑥ mission function (depends on mission)

• **Standard components to be implemented on each panel**:
  - Power-related: solar cells + small battery
  - Information-related: inter-panel communication components (local CPU taking charge of bus controller)

• **Other important factors**:
  - Power demands and generations are not balanced in each panel (e.g., Mission, communication panels require lots of power)
    → Real time power distribution between panels is indispensable
  - Many CPU exists including local CPUs and main OBC
    → System management by multi-CPUs and enable grid computing
  - Component shape should be aligned in the flat panel structure
    → 1-axis controller (gyro, wheels, magnetic torquer, etc) in 1 panel
## Example Requirements for Each Type of Panel

<table>
<thead>
<tr>
<th>Component</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBC+memory</td>
<td>Speed &gt;30MIPS, Memory size &gt; 1GB</td>
</tr>
<tr>
<td>Battery</td>
<td>Life time &gt; 1 year in 30 %DOD &gt;3W</td>
</tr>
<tr>
<td>Solar cells</td>
<td>&gt; 10 w per panel</td>
</tr>
<tr>
<td>Communication</td>
<td>Downlink &gt; 250kps (in S or higher freq.)</td>
</tr>
<tr>
<td>Orbital control</td>
<td>Safe propellant, ISP&gt;100s、T&gt;0.1N</td>
</tr>
<tr>
<td>Inter-panel com.</td>
<td>1 Mbps, redundancy</td>
</tr>
<tr>
<td>Information line</td>
<td>Weight &lt; ½ of conventional harness</td>
</tr>
<tr>
<td>Structure</td>
<td>Weight ~ conventional fraction(10%)</td>
</tr>
</tbody>
</table>
(2) Interface Study
Requirements as to Four Interfaces

• Mechanical Interface
  – Reliable folding/extension in space environment
  – Low shock extension and latch in several angles

• Electrical Interface
  – Self-supply within each panel in principle.
  – Autonomous power re-distribution between panels

• Information Interface
  – Distributed agent architecture, Plug-In simplicity
  – Fault tolerance, grid computing

• Thermal Interface
  – Suppress temperature difference between/within panels
Requirements for Four Interfaces

• **Mechanical Interface**
  – Reliable folding/extension in space environment
  – Low shock extension and latch in several angles

• **Electrical Interface**
  – Self-supply within each panel in principle.
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• **Information Interface**
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• **Thermal Interface**
  – Suppress temperature difference between/within panels
Mechanical Interface (1) - Launch locked panels and extended configuration
Mechanical Interface (2)

- **Main structure** (for components package) and **Link Module** at four corners
- Plug-in between Link module and main structure
- Link module variety (direction, angle):
  - 90, 180, 270 degree / two directions

![Diagram of main structure and link module](image1)

**Current model of main structure**

**Current model of link module**
Panel Trial Design

Design by CAD (Pro/Engineering) for interaction checks
Fabricated Panel (1st Round Trial)

Component Bed (Outer Surface)  Component Bed (Inner Surface)  After Extension

Attachment holes for components

Hinge can be attached in two directions
Example of Panel - CPU Panel

- CPU
- Heat Conductor
- Battery
- CAN bus controller (local CPU)
Requirements for Four Interfaces

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Electric Power Re-distribution Plan

Local CPU control

Power By Pass Circuit
Electric power is self-supplied within each panel in principle.

Electric power is managed efficiently by distributing surplus electricity through the bus line to the panels that run short of electric power.
Electric Power Network for PETSAT(2)

- **Battery**
  - Li-Ion batteries of COTS products
    - Self-discharge is almost nothing.
    - Energy density to the mass is high.

- **Solar cells**
  - GaAs solar cells is used.
  - Solar cells on the panel are divided into 4 strings and each string has 1 battery to use batteries more efficiently. Because it is possible to make a shadow over solar cells depending on configurations.

The shadow disturbs charging of the batteries under string-1 and -2, but the batteries under string-3 and -4 can be charged without the disturbance.
Electric Power Network for PETSAT(3)

- Electric power controller (1/2)

(a) PPT circuit

- Each string of the solar cell has one PPT circuit.
- PPT circuits are controlled by CPU of each panel.

(b) Charging circuit

- Charging circuits are COTS products with small size and easy circuit.
- CPU of each panel controls charging circuits by cooperation with OBC to manage the electric power balance of the whole satellite. Consequently, the battery life can be extended by suppression of excess charging.
Electric Power Network for PETSAT(4)

Electric power controller (2/2)

(c) Reed relay network

For example

- Reed relay 1 breaks down while disconnected
  
  The line with reed relay 3 and 4 is used.

- Reed relay 1 breaks down while connected
  
  Reed relay 2 is kept in disconnected state and the line with reed relay 3 and 4 is used.
Requirements for Four Interfaces

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• Electrical Interface
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• **Information Interface**
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  – Fault tolerance, grid computing

• Thermal Interface
  – Suppress temperature difference between/within panels
CPU on OBC panel has the top priority to manage the other panels, so should be the most fault tolerant. In case of OBC panel failure, one of the other CPUs take over the manager’s role.

Distributed computing is made in case large calculation is required.
Concept of Information Flow
CAN Bus Test Board Development

CAN Bus Evaluation Board

With CPU Board and Connected CAN Bus
Requirements for Four Interfaces

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• Thermal Interface
  – Suppress temperature difference between/within panels (current target is less than 5 C deference)
Worst Case Analysis

Solar heat insertion on one panel and no solar power insertion on the neighbouring panel (90° bent)

5 degree deference can be achieved using:

Inter-panel heat transfer: “Graphite Sheet” because of its flexibility

Intra-panel heat transfer: ”Heat Lane Plate” because of its high heat conductivity
To Improve Heat Transfer

“Heat Lane Plate”
Heat Conductance Capability

\[ 2.96 \times 10^6 (W/m^2) \]

Heat Absorption Rate

33 Z ~ 5N
Thermal Simulation Results for Worst Case

Sun Shining Side

22°C  26°C  30°C  34°C
Heart Conductance Plan

Heat Lane Plate

4 Layers

Graphite Sheet

4 Layers on the rear side
Example Application of PETSAT (1)
- Thunder Location -

Ground Observation System

Satellite Observation System

Direction Estimation

Data Storage and Preprocessing

Location of Thunder

Wide band Antenn+ Filter+Amp

A/D Converter

Signal Processing

Difference of arriving RF phases has information about the relative direction of the RF source
Development Plan

• Funded by NEDO for 2003 ~ 2008
• Joint Project by SOHLA (Higashi-Osaka), Univ. of Tokyo, Osaka Univ., Otowa Denki
  – Combination of university’s system engineering and small manufacturing company’s special technologies

• SOHLA-1 (~ 2007)
• SOHLA-2 (~ 2009) for on-orbit test of PETSAT concept and panels

Image of SOHLA-2