A Novel Satellite Concept “Panel Extension Satellite (PETSAT)”
Consisting of Plug-in, Modular, Functional Panels

Shinichi Nakasuka, Hironori Sahara
Department of Aeronautics and Astronautics, University of Tokyo
Hongo 7-3-1, Bunkyo-ku, Tokyo, 113-8656, JAPAN; +81-3-5841-6590
nakasuka@space.t.u-tokyo.ac.jp

Yoshiki Sugawara
Department of Mechanical Engineering, Aoyama Gakuin University
5-10-1, Fuchinobe, Sagamihara, 229-8558, JAPAN; +81-42-759-6440
sugawara@me.aoyama.ac.jp

Takeshi Morimoto
Division of Electrical, Electronic and Information Engineering, Osaka University
2-1, Yamada-gaoka, Suita, Osaka, 565-0871, JAPAN; +81-6-6879-7690
morimoto@comm.eng.osaka-u.ac.jp

Kanichi Koyama, Hideaki Kikuchi, Takanori Okada, Hidenori Tanaka, Shinichi Sato, Chisato Kobayashi
SOHLA
Creation-Core 2102, Aramoto-kita 50-5, Higashi-Osaka, 577-0011, JAPAN; +81-6-6747-8081
koyama@sohla.com

ABSTRACT
A novel concept of satellite design, named "PETSAT," is proposed in this paper. In this concept, a satellite is made of several "Functional Panels" each of which has a special dedicated function. By connecting these panels by reliable connection mechanism in "plug-in" fashion, the total integrated system as a whole has a satellite function. Various combinations of functional panels, (for example, one communication panel + three attitude control panels + two thruster panels, etc.) provide flexibility to deal with various mission requirements, even though the basic panels are the same for various missions. First, PETSAT concept is described and its strong points and shortcomings are discussed. Next, several key technologies are explained in more detail, including panel structures, deployment mechanism, power distribution network, information network architecture and thruster system. Finally the current status of development of SOHLA-2, an in-orbit demonstration satellite for PETSAT concept planned to be launched in 2008-2009, will be briefly described.

CONCEPT OF PETSAT
A novel concept of satellite design, named "PETSAT," is proposed in this paper. In this concept, a satellite is made of several "Functional Panels" each of which has a special dedicated function. By connecting these panels by reliable connection mechanism in "plug-in" fashion, the total integrated system as a whole has a satellite function. Various combinations of different kinds of functional panels, sometimes in different quantity more than one, provide flexibility to deal with various mission requirements, even though the basic panels are the same for various missions. These panels are stowed during launch into a small volume (left figure in Fig.1), and are extended on orbit (right figure in Fig.1), realizing a satellite which requires a long boom part or a large area.

Figure 1: Concept of PETSAT before deployment (left) and after deployment (right)
PETSAT intends to change the satellite development cycle in the following way:

1) Each functional panel can be produced in mass quantity to reduce cost and improve reliability. And the produced panels are to be stocked.
2) When a certain mission is given, the satellite bus suitable for the mission requirements can be configured only by connecting the appropriate panels in appropriate quantity in "plug-in" fashion without much effort on ground test of the total system.

This "semi-customize" type satellite production process is expected to reduce required time and workload dramatically, resulting in a drastic reduction of the satellite cost and development time.

Mass production of the panels is the key to reduce cost and to improve reliability, but in the conventional satellite concept, mass production is difficult even in subsystem level due to the wide variety of the mission requirements. PETSAT tries to make this possible by modularizing the various basic subsystem functions into "Functional Panels," and by dealing with the variety of mission requirements with the quantity of the utilized panels of different functions.

The concept of PETSAT was initially proposed at the Satellite Design Contest in 2002, where the concept and design was awarded "the Best Design Award." Five year research project of PETSAT started in 2003, supported by NEDO subsidy, in collaboration of University of Tokyo, Osaka University and manufacturers' community of Higashi Osaka, and JAXA. In addition to the basic concept refinement and technology development, we are also examining commercial applications of PETSAT, one of which is lightning observation system described later.

In the following sections, first, some technical issues to be solved to realize PETSAT will be shown, followed by the results of conceptual study. Then the technological aspects are described in more detail, including power distribution network, information network architecture, structure, and thruster system suitable for PETSAT. Finally in-orbit technology test and demonstration satellite named “SOHLA-2” will be briefly described.

TECHNICAL ISSUES

Overall Technical Issues

The key technical issues to realize PETSAT include:

1) How to modularize the satellite bus functions into different panels: for example, whether battery and solar cells should be implemented in a separate functional panel such as “an electric panel” or should be equipped in every panel as standard components.
2) The standard panel structure which provides enough thermal and structural environment to different kinds of functional panels: for mass production and cost saving, a standard design should be applied to different functional panels.
3) Interface between panels: four kinds of interface, mechanical, electrical, information, and thermal interfaces should be carefully designed so that the plug-in simplicity of PETSAT can be achieved.

Requirements on Panel Interface

As to the interfaces, the following requirements should be satisfied.

(a) Mechanical Interface
Panel connection and deployment/latch mechanism, which is very reliable, fault tolerant, soft and with high accuracy is required. Also it is required that the panels can be easily plugged-in. The accuracy of the angles between panels after deployment should be a certain level so that the initially planned satellite shape can be achieved. Finally, in order to achieve various shape of the satellite (see Fig.2), the sequence of the panel deployment should be carefully designed because otherwise the deployment becomes stacked. Some mechanism to control the sequence is required which assures that, for example, the deployment of panel A and B starts after panel C is deployed from panel D, etc.

(b) Electric (power) Interface

Figure 2: Various shape realizable by PETSAT
In principle, the electric power required in each panel should be generated by solar cells of the same panel, but in many cases power should be transferred from one panel to another panel. PETSAT should have the capability to autonomously transfer power between panels. Reliability of power line is another important issue, which should be realized by carefully designed redundancy.

(c) Information Interface

Communication between panels is essential for PETSAT. The information line should be very reliable and should have enough communication capacity to deal with the flow of house keeping data as well as mission data. Each panel should have a certain level microprocessor for controlling this information traffic as well as managing the information flow inside the panel. So the total system becomes a multi-processor system and the architecture to manage such large number of CPUs should be carefully designed so that the strength of the distributed system such as fault tolerance or capability of grid-computing can be pursued as much as possible. The information line can be either wired bus line or RF line, but after careful considerations, wired bus line has been adopted. The detailed design will be given later.

(d) Thermal Interface

Thermal coupling within and between panels should be made very strong so that the temperature difference between each part of satellite should be as small as possible. The paper indicated that this is the best "general" strategy for thermal control because (1) the thermal environment is different from missions to missions, and (2) there are not many design freedom for PETSAT thermal control because the surface of the panel is almost covered by solar cells.

In this paper, the electrical power network, information network design, and structure will be highlighted.

Distributing Functions into Panels

In PETSAT, some satellite functions may be implemented as “specialized components” in only a certain panel, and other functions may be implemented as “standard components” in all the types of panels. Therefore, one of the important research issues is how to distribute various satellite functions into different type of panels.

To determine this, the following requirements coming from PETSAT features should be observed:

1) Interface simplicity: panels of different types can be plugged-in in any quantity while satisfying the requirements on the four type of interfaces as described before.
2) Functions enforced by increasing the number of panels: for example, the attitude control capability should be enforced by the number of ACS panels employed
3) Standard panel structure: the structures of different panels should be almost the same so that the mass production of the panel structure is possible.
4) Flat shape of the panels: in order to be deployable, the panels should be flat, which requires that, for example, only one axis wheel can be implemented in one panel.
5) Fault tolerance and graceful degradation: the satellite functions can be maintained in degraded level even in case of failures of certain panels or interface component (such as information line, power line, hinge, etc).

After the examinations taking into account how several example missions can be achieved by PETSAT, the following distribution strategy has been found appropriate.

1) The variety of panels are as follows: ( ) shows the specialized functions implemented in each panel
   (a) Communication Panel (transmitter, receiver and antenna)
   (b) Attitude Control Panel (one axis reaction or momentum wheel and three axis magnetic torquers, gyros, and sun sensors, realizing minimum three axis stabilizing capability in one panel.
   (c) Thruster Panel (thruster, valve, pipe and propellant tank)
   (d) Mission Panel (different for different missions)

2) The following components are implemented as “standard components” to be implemented in all types of panels.
   (e) solar cell, small battery and power management system
   (f) microprocessor to play as C&DH system within the panel as well as manage inter-panel communication

3) As to the power, each panel’s solar cell supplies solar power to the panel, and the residual power can be transported to any other panel automatically

4) As to the information management, many CPUs in different panels had better be efficiently utilized for realizing fault tolerance, graceful degradation, and for grid computing if a certain panel requires heavy information processing.
EXAMPLES OF PETSAT APPLICATIONS

Before going into technical details, let us briefly give description of two example missions realizable by PETSAT.

**Interferometric Positioning System**

If a certain RF wave arrives at the antennae located with proper separation on PETSAT, then the difference of the arriving time or “phase difference” provide the information as to the relative direction of the RF signal source in respect to the PETSAT. If there are three antennae which are not located in one line, then the direction of the signal source in 3D space can be estimated. The accuracy of the direction estimation depends on the distance between the antennae (base line) and the knowledge about the relative positions of these antennae in respect to the satellite body frame. The long base line can be achieved in PETSAT by extension of several panels between the panels which implement these antennae (Fig.3) or by extending booms (Fig.4), and the relative positions of antennae can be estimated by calibrating this sensor system using the generated signal from a certain point of PETSAT. Figure 3 and 4 shows one example; interferometric observation of where lightning occurs. Lightning causes clusters of impulsive electro-magnetic waves in VHF (very high frequency) band, and by detecting the direction of VHF sources, which is equivalent to the lightning monitoring, we may be able to predict where lightning will possibly occur in near future.

[Figure 3: Lightning Observation PETSAT (Panel)](image)

[Figure 4: Lightning Observation PETSAT (Boom)](image)

If we want to obtain the geo-location of the RF source on the Earth, then the PETSAT should know its attitude precisely. Several type of navigation sensors for attitude can be employed, including IRU (gyros), magnetometers, Earth sensor, sun sensor and star sensors. However this interferometric sensor itself can be also a precise navigation sensor, i.e., attitude can be estimated by obtaining with this interferometric antennae a RF signal generated by the ground station whose position is known. This calibration method is now under study.

**“Containers” for Multiple Mission Launchers**

One of the great merits of PETSAT is that multiple mission systems can be developed in parallel as different “Mission Panels” and plugged in together to the same PETSAT to realize a satellite with several missions. Mission Panels will be developed by different customers using provided panel boxes with standard components inside them. These mission panels are categorized into several groups having similar requirements for attitude control and orbit. And at each PETSAT launch opportunity, mission panels in one category are plugged-in to the PETSAT bus systems consisting of several functional panels. This is just like many “train containers” having different goods inside them connected to the main electric or diesel trains. Example of such missions include in-orbit test or demonstration of new parts or equipment, space sciences, micro-gravity experiments or “personal box,” etc.

Hereafter, some important technologies of PETSAT will be described in more detail

**ELECTRIC POWER NETWORK**

**Overview**

Figure 5 shows the overall architecture of electric power distribution systems. Each panel has a battery, Battery Charge Regulator (BCR), solar cells, voltage regulator and power distribution module as “standard components.” The output line of BCR, which is input to the battery, is connected between panels and so made common in the whole PETSAT. As a result, all the batteries in the whole PETSAT are in parallel connection, keeping the same voltage. Electric power generated in the solar cells of one panel might be insufficient or be too much for what the specific panel really needs. By using inter-connection as in Fig.5, electric power is managed efficiently by making surplus electricity automatically flow through the inter-panel power line to the panels that run short of electric power. The Panel Control Module (PCM), which manages
information flow inside the panel (shown later), obtains the status (such as voltage, temperature, solar cell outputs) within the power related system inside the panel, and when a certain anomaly occurs, it can on/off a certain switches inside the panel to control the intra-panel as well as inter-panel power flow. When the battery voltage (common to all the panels) becomes below a certain level (say $P_1$ volt), PETSAT will go into “low power mode” first and then into “safe mode” until the battery voltage becomes above a certain threshold which is larger than $P_1$.

Information network of PETSAT has been designed by considering the following factors.

(a) High reliability

(b) Usage of COTS hardware/software which is widely utilized with efficient development support tools and software library.

(c) Two layer (inter-panel and intra-panel) structure in nature.

System Overview

Taking these factors into consideration, Renesas’s SH series microprocessor, CAN (Controller Area Network) bus system and I2C have been adopted as the back bone. Figure 6 shows the overall architecture of the information network and Fig.7 shows the information management system inside each panel.

Solar cells

GaAs solar cells are mounted on both sides of the panel. PETSAT is a satellite which can form a three-dimensional configuration. Therefore, it is possible for certain panels to make a shadow over solar cells of other panels depending on sun direction. For that reason, solar cells on one side of the panel are divided into several strings to use them efficiently so that a certain amount of power can be generated even if some solar cell area is covered with a shadow.

INFORMATION NETWORK DESIGN

Requirement
(to/from the ground), etc. Local components usually have low power CPU such as H8 or H8S which have I2C controller inside.

Two CPUs named “Panel Control Modules (PCM)” manage the information inside the panel and information flow between panels. The outputs of these two PCMs are compared in CPUI (CPU Interface), which monitors health status of PCMs. When CPUI detects some discrepancy between the outputs, it resets both the PCMs. In addition to that, PCM has self-test functions, and when it detects its own anomaly, it resets itself. CPUI records the number of resets for two PCMs, and if the number of resets exceeds a certain threshold, this specific PCM will never be powered-on. CPUI is configured using a small scale FPGA.

**CAN Bus System**

CAN bus has been developed since 1980s and standardized in the 1990s, and is currently one of the standards in the automotive industry. Can bus has network layer model based on OSI (Open Systems Interconnection) reference model. Typical features of CAN bus are as follows:

- Automatic error detection and message retransmission
- Multi-master layer has network architecture
- Transmission of all messages by broadcast method to improve the integrity of data

By introducing CAN, PETSAT can keep high reliability, redundancy, and easiness to realize inter-panel communication functions. Communication speed of CAN bus is now set as 650 kbps, considering “derating”.

**Semi-distributed network system**

Network system is constructed with use of CAN that transmits all messages by broadcast method and has the function of automatic message retransmission. Each data is not transmitted from each panels in random order, but handled under less-restricted control to use core functions (communication, mission, power and so on) effectively.

A set of PCMs in a certain panel is assigned with “OBC” role, which manages the whole satellite, including sequencing the multiple missions, treating anomalous situations, and commanding attitude/orbit control requirements, etc. If some anomaly is found in the operation of this OBC, then the OBC function is taken over by the second prioritized PCM sets in different panel.

**STRUCTURE**

**Panel structure**

To satisfy requirement for PETSAT, following issues are focused on to develop the panel structure.

- Each panel has standard structure except for mission panel.
- Panel structure has light weight and target weight is 20% of that of a whole panel (average).
- Enough stiffness and strength is prepared for load during launch.
- Cost for production should be low.

During this project, three types of panel structure have been developed. Figure 8 and Figure 9 are prototypes of panel structure and Figure 10 shows the current engineering model of panel structure.

Prototype model A is made by metal cutting work. Inside of the panel, standard screw hole is prepared for mounting devices. Because of technology of metal cutting work, variable shape can be feasible. However, cost for mass production is very high compared to other method of production.

Prototype model B is also made by metal cutting work. But the model is improved to achieve more low cost and light weight structure compared to Prototype model A. However, thermal connection within panel becomes weak, thus other equipment is required to strengthen thermal connection, that is, whole mass of one panel becomes heavy as a result.

Based on the experiences of model A and B, an engineering model shown in Figure 10 has been developed by sheet metal working. Therefore, cost for mass production decreases dramatically compared to two prototypes. Moreover sheet metal working enables strong thermal connection between main surface and side surface (Figure 10) because vertical connection of plates can be realized from one sheet metal. Inside of the panel also has standard screw hole for mounting devices. Area for mounting common devices, i.e. devices for power and information, is partially separated by thin wall, which has a role to strengthen the rigidity of the panel. The size of one panel is also improved to make it possible to mount necessary components for PETSAT. Feasibility of component placement within current panel structure has been also confirmed with mock-ups of components (Fig.11). Currently the standard size of the panel is determined as 350 x 350 x 50 mm except for Mission Panel.
As is clear from aforementioned concept of PETSAT, optimization can not be realized easily. Therefore, stiffness of each panel and connected panel with stowed shape is designed with some margin. Otherwise, some methods to strengthen them will be prepared, i.e. standard stiffener and so on. To solve such kind of problem about stiffness, analysis and several vibration tests have been carried out.

Table 1: Comparisons of each model

<table>
<thead>
<tr>
<th>Model</th>
<th>Prototype model A</th>
<th>Prototype model B</th>
<th>Engineering model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>4*</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Weight</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Specific strength</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Natural frequency (without component)</td>
<td>1 (400.0Hz)</td>
<td>3 (65.6Hz)</td>
<td>2 (137.5Hz)</td>
</tr>
<tr>
<td>In-plane heat conduction</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Heat transfer to side surface</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Space efficiency for mounting devices</td>
<td>4 (1.5Kg/#)</td>
<td>1 (0.15Kg/#)</td>
<td>2 (0.22Kg/#)</td>
</tr>
</tbody>
</table>

* indicates 1(excellent) 2(good) 3(fair) 4 (bad).

Figure 8: Prototype model A
Height of panel: 50mm

Figure 9: Prototype model B

Figure 10: Engineering model

Figure 11: Panel inside structure with components
Figure 122 shows principle of deployment mechanism for PETSAT, which consists of axis, torsion spring and fit. Torsion spring deploys the panels and fit determines the deployment angle. The equilibrium point of the torsion spring is larger than the deployment angle to keep force at deployment angle. Thus, the deployment angle is fixed by force of torsion spring and the reliability of deployment is high because the system is simpler than the model with latch mechanism.

Moreover there is possibility that surface accuracy of the fit cause error of deployment angle. Under some assumptions, acceptable surface accuracy is estimated as shown Figure 14. In the estimation, it is supposed that hemisphere with radius \( d \) on the surface of fit determines the surface accuracy of the fit. Thus, \( d \) causes error of deployment angle \( \phi \). Then, relations of parameters are derived as follows.

\[
\Delta \phi = \frac{L}{D} \quad (1)
\]
\[
d \sin \theta = L \quad (2)
\]

Here, the value of \( L \) and \( \theta \) are supposed to be practical value as shown in Figure 14. \( \Delta \phi \) is deployment angle error required to be less than 0.5 degree. Then, the value of \( d \) is derived as follows

\[
d < 0.62 \text{mm} \quad (3)
\]

Recent machining technology has very high accuracy, and that required value of \( d \) is feasible value.

In consideration of aforementioned issues, CAD model of deployment mechanism is designed as in Figure 15. For deployment of one panel, 2 sets of deployment mechanism are attached between two panels. Each set has symmetry structure and this enables deployment mechanism to fix the displacement toward the direction of axis (Figure 16).

Other feature of deployment mechanism is as follows:

- To avoid vacuum metalizing, axis of the mechanism is coated by solid lubricant.
- For variety of deployment angle, interface for attachment has special shape depends on the angle (Fig.17).
Based on aforementioned designs, engineering model of deployment mechanism is developed (Fig.18).

Deployment test under micro gravity and vibration test about developed deployment mechanism was carried out. They show enough validity of the mechanism. Hereafter, additional test with more detailed condition is planned in September 2007 to analyze more detailed characteristic of the mechanism in order to improve the design of the Flight Model.

A concrete way to realize SAFETY FIRST is to reduce the risk of propellant, especially oxidizer, which risk means toxicity, causticity, and explosibility in particular. In these days safer propellants are proposed but at least one of them is unavoidable: Hydrazine permits toxicity, Hydrogen Peroxide accepts causticity, and HAN admits explosibility. We decided Hydrogen Peroxide solution of middle-level concentration up to 60% as propellant or oxidizer. As to fuel, we chose Ethanol, which is less toxic than methanol, less caustic than hydrazine, and less explosive than acetone or HAN. Lower risk means lower performance of propulsion but higher safety and
lower costs, so we permit performance degradation to some extent respecting the SAFETY FIRST policy.

We estimated their performance using CEA and actually resulted in 50 sec of Isp with 500 mN-class thrust and 120 sec of Isp with 1 N-class thrust in the cases of monopropellant and bipropellant propulsion, respectively. Now we are testing the propulsions as shown in Fig. 19, and designing and developing PFM of a compact volume propulsion system and its controller for PETSAT, shown in Fig.20 and Fig.21.

**Figure 19:** Captive tests of monopropellant and bipropellant propulsion for PETSAT

**Figure 20:** Propulsion system for PETSAT

**Figure 21:** Controller of the propulsion system for PETSAT

**SOHLA-2 IN-ORBIT DEMONSTRATION PLAN**

**Overall Configuration**

The research to develop PETSAT technologies has been funded by NEDO, Japanese governmental organization, with an intention to complete SOHLA-2, the first experimental PETSAT, at the end of the 5-year project. Figure 22 shows the current planned configuration of SOHLA-2. It consists of five panels, a bus functional panel(BUS-P), a communication panel(COMM-P), an attitude control panel(ACS-P), a thruster panel(PROP-P) and a mission panel(MISN-P), its main objectives being the experiment and demonstration of the important technologies of PETSAT. In addition, as a scientific mission, lightning monitor experiment using VHF digital interferometer has been adopted. Table 2 shows the basic specifications of SOHLA-2.

**Figure 22:** Planned configuration of SOHLA-2

<table>
<thead>
<tr>
<th>Mission</th>
<th>Mission antenna</th>
<th>COMM-P</th>
<th>BUS-P</th>
<th>ACS-P</th>
</tr>
</thead>
<tbody>
<tr>
<td>During Launch</td>
<td>Gravity-gradient boom</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MISN-P</td>
<td>PROP-P</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 2: Basic specifications of SOHLA-2

<table>
<thead>
<tr>
<th>Items</th>
<th>Values</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OVERALL</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>&lt; 50kg</td>
<td></td>
</tr>
<tr>
<td>Size (stowed)</td>
<td>350x350x500 mm</td>
<td></td>
</tr>
<tr>
<td>Size (deployed)</td>
<td>350x50x1400 mm (Antenna length is 5m)</td>
<td></td>
</tr>
<tr>
<td>Size (one panel)</td>
<td>350x350x50 mm, 350x350x100 mm (four panels)</td>
<td></td>
</tr>
<tr>
<td><strong>BUS FUNCTION PANEL (BUS-P)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Configuration</td>
<td>Same system as CubeSat “XI”</td>
<td>Space proven for over 3 years</td>
</tr>
<tr>
<td>Communication</td>
<td>Uplink: (FM) 145MH 1200bps Downlink: (FM,CW) 437MHz 1200bps</td>
<td>Amateur Frequency Band</td>
</tr>
<tr>
<td><strong>LOCAL CPU</strong></td>
<td>Pic16F877</td>
<td></td>
</tr>
<tr>
<td><strong>COMMUNICATION PANEL (COMM-P)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downlink (S-band)</td>
<td>0.1W 500 bps PCM-PM</td>
<td>for H/K for mission</td>
</tr>
<tr>
<td>Uplink (S-band)</td>
<td>500 bps PCM-PM</td>
<td></td>
</tr>
<tr>
<td>Antenna</td>
<td>Phased array patch ant. Monopole whip antenna</td>
<td>for BPSK for PSK-PM</td>
</tr>
<tr>
<td><strong>ATTITUDE CONTROL PANEL (ACS-P)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensors</td>
<td>Magnetometer 3-axis mechanical gyros 6 sun sensors</td>
<td>Accuracy is roughly 0.5°</td>
</tr>
<tr>
<td>Actuators</td>
<td>Magnetic Torquer Reaction Wheel (TBD)</td>
<td></td>
</tr>
<tr>
<td>Local CPU</td>
<td>H8/3694F (Renesas)</td>
<td></td>
</tr>
<tr>
<td><strong>THRUSTER PANEL (PROP-P)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>Ethanol (C2H5OH) can be others</td>
<td></td>
</tr>
<tr>
<td>Oxidizer</td>
<td>H2O2 (stabilizer included)</td>
<td>middle-level concentration (&lt;60%)</td>
</tr>
<tr>
<td>Thrust</td>
<td>500 mN / 1 N</td>
<td>For mono / bi-propellant</td>
</tr>
<tr>
<td>Total ΔV</td>
<td>500sec / 120sec</td>
<td>mono-/bi-propellant</td>
</tr>
<tr>
<td>Local CPU</td>
<td>H8/3694F (Renesas)</td>
<td></td>
</tr>
<tr>
<td><strong>MISSION PANEL (MISN-P)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A/D Channels</td>
<td>2 (for two antennae) max 3 possible</td>
<td></td>
</tr>
<tr>
<td>Antenna</td>
<td>Conic-shape 2 antennae Separation: 5m</td>
<td></td>
</tr>
</tbody>
</table>

The shape and configuration of the five panels is determined considering the gravity gradient torque, solar power generation (assuming operation in a sun-synchronous orbit), required attitude during the lightning observation, position and orientation of communication antennae (in COMM-P and BUS-P), thrust vector direction, and how they can be stowed before separation from the rocket, etc. The five panels are stacked during launch such as in the upper left figure in Fig.22 using a separation mechanism such as in Fig.23. The column type holders at the four corners will bend and release SOHLA-2 by cutting wires using pyro wire cutters. The length of these column holders can be changed to deal with various number of stacked panels. The yellow part is the part attached to the rocket, which will remain on the rocket together with the column holders, which avoid generating additional debris. The planned operation sequence after the separation is as follows.

**Figure 23: Standard separation system for PETSAT**

1) SOHLA-2 detects separation from the rocket, when BUS-P and the Base-unit of each panels is turned on.

2) Soon (such as 30 minutes) after the separation from the rocket, the timer triggers the panel deployment process; the panel connection hinges cut the launch rock wires and start deploying panels with spring forces.

3) BUS-P deploys its antenna and check-out of BUS-P is performed, whose results are sent to the ground using its own communication system.

4) The inter-panel communication between Base-units of each panel and BUS-P over CAN bus starts, whose results will be collected to the BUS-P and sent back to the ground using BUS-P communication system.

5) Mission antenna is deployed, and final configuration is achieved.
6) Each panel performs initial check-out, and based on the results and the amount of really generated power, the experiments of each panel are planned and performed one by one for about 10 weeks.

7) Lightning observation and data downlink experiment is performed using COMM-P’s communication system.

8) After all the nominal experiments are completed, additional “advanced” experiments will be performed such as collaborative functioning of PROP-P and ACS-P, etc.

**Bus Functional Panel (BUS-P)**

BUS-P acts as “Bus system” for SOHLA-2, performing such tasks as sequencing the experiments, collecting H/K data from each panel and send to the ground, getting commands from the ground and send them to appropriate panels, and especially send back to the ground some data even if SOHLA-2 is in anomalous situation. The reliability and tolerance in space environment is essential, and therefore the bus system of University of Tokyo’s CubeSat “XI-IV” and “XI-V” has been adopted with least modification. This very small bus has been surviving in space for more than three and a half years (for XI-IV case) and one and half years (for XI-V case). It has its own battery and solar cells in addition to those inside the Base-unit common to all the panels, and even if the Base-unit does not function correctly, BUS-P can operate with the same functions as XI-IV and XI-V.

Its communication system developed by Nishi-musen, also the same as one demonstrated in XI-IV and XI-V, operates as the primary communication system to/from the ground before the S-band communication link is established. BUS-P also manages the battery voltage of the whole SOHLA-2 and when the severe shortage of the power is detected, BUS-P makes the SOHLA-2 come into safe-mode, in which only BUS-P operates in low power consumption mode.

**Communication Panel (COMM-P)**

COMM-P has newly developed three RF transceivers, one PCM-PM transmitter for H/K data, one BPSK high data rate transmitter for mission data, and one PSK-PM command receiver. These equipments have not been demonstrated in space before and therefore the usage of them is one of missions for SOHLA-2. Figure 24 shows the package of the three transceivers plus patch antennae. The whole system is configured within 300 x 300 mm. The RF power is 2W (input is less than 20W) for BPSK and 0.1W (input is 0.5W) for PCM-PM transmitters.

![Figure 24: Transceiver and antenna package](image)

**Attitude Control Panel (ACS-P)**

ACS-P has within just one panel the capability of three-axis stabilization with sensors and actuators for three axis. The gyros are primarily utilized for rate damping of SOHLA-2 as well as for IRU (Inertial Reference Unit) augmented by sun sensors. Only a wheel, either a raction wheel or a momentum wheel, is implemented in just one axis, considering its power and size requirements. The anticipated accuracy of attitude estimation is about 0.5 degree. SOHLA-2 will be stabilized by gravity gradient stabilization (see Fig.22).

**Thruster Panel (PROP-P)**

Please see the description in the “THRUSTER PANEL” section before.

**Mission Panel (MISN-P)**

SOHLA-2 adopts as a scientific mission the lightning observation using VHF electro-magnetic wave. As is described in Fig.5, two impulsive VHF waves caught by two antennae can provide one dimensional information, the angle of incidence, and therefore three antennae are required to detect the direction of the lightning position without any ambiguity. However, due to the resource limitation of SOHLA-2, experiment with two antennae as in Fig. 22 is currently planned, though there is still possibility to add the third antenna.

Figure 25 shows the system description of the lightning observation system. Received RF bursts are A/D transformed and manipulated in FPGA and DSP to detect the phase differences between RFs detected by different antennae, which are utilized to estimate the direction. For more detail, please refer to previous papers. This type of experiments have been performed on ground, but never been done from the space before. The full A/D transformed data as to VHF waveforms as well as estimated lightning location data are planned to be downlinked.

Nakasuka
UNIVERSITY OF TOKYO’S NANO-SATELLITE ACTIVITIES

Finally other nano-satellite activities in University of Tokyo is briefly overviewed in this section. Figure 26 shows the roadmap of the activities. Two CubeSat, “XI-IV” and “XI-V” (Fig.27) were launched in 2003 and 2005 respectively, which are still working in good conditions in space.

XI-IV, which has already survived for more than 3 years and 11 months (as of June 2007), has validated our nano-satellite system’s architecture based on COTS parts. The photos of the Earth taken by XI-IV (Fig.28) show the possibility of usage of such Nano-satellites for practical applications. The second satellite “XI-V” is almost the same design as XI-IV, except for the enhanced camera capability and a new mission of in-orbit test and demonstration of CIGS solar cells developed by JAXA. This test result up till now is very encouraging, which shows the promising applications of nano-satellites to quick and low cost in-orbit test bench for new technologies, parts and equipment.
Our third satellite, named “PRISM,” aims for remote-sensing with the ground resolution of 30 m using a refractive optical system with 50 cm focal length. The key technology is an extensible boom with a lens at its end, which is already developed and now under tests using micro-gravity flights. PRISM has been selected as one of 6 micro/nano-satellites to be launched in piggy-back on Japanese H-IIA rocket in 2008.

The fourth satellite, named “Nano-JASMINE,” has an astronomical mission to make a 3D precise star map. The requirement for attitude and temperature stability is quite severe, which has been achieved by special attitude control system and structural design. The development is now at BBM to EM phase (as of June 2007), aiming for launch in 2008 or 2009, in collaboration with National Astronomical Observatory of Japan. The detail will be given in another presentation of this symposium.

PETSAT is our fifth satellite. The idea of PETSAT won the first prize at the 10th satellite design contest of Japan in 2002. The primary development team consists of small industries and students mainly in Osaka area, and University of Tokyo

CONCLUSIONS

The concept of PETSAT will open a new way of satellite development, which is expected to reduce the time and cost required for integration and ground test. The key technological issues include the realization of four important interfaces between panels; mechanical, electrical, information and thermal interfaces. This paper describes the basic concepts of PETSAT, its technological issues, various technologies developed up till now as well as SOHLA-2, in-orbit demonstration satellite planned to be launched in 2008-2009. PETSAT concept is an attempt to change the satellite development way from “Closed Integral” to “Open Modular” type.

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References