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

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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 with a reliable connection mechanism in plug-in fashion, the total integrated system has a full satellite’s function. Various combinations of functional panels, (for example, two CPU panels + one communication panels + three attitude control panels + two battery panels, etc.) provide flexibility to deal with various mission requirements, even though the basic panels are the same for various missions. The concept, technical issues and conceptual study results of PETSAT will be discussed.

1. 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 has a full satellite’s function. Various combinations of different kinds of functional panels, sometimes with multiple instances of identical panels, 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), potentially realizing a satellite with a large antenna, large solar cell area or large boom.

PETSAT intends to change the satellite development cycle in the following way:

1. Each functional panel can be produced in mass quantities so that the reliability can be improved, and the produced panels can be stocked.

2. When a certain mission is given, the satellite bus suitable to the mission requirements can be configured only by connecting the appropriate panels in appropriate quantities in plug-in fashion without much effort needed in ground test of the total system.

This semi-customizable satellite production process is expected to dramatically reduce required manufacture and test time, as well as workload, resulting in a drastic reduction of the individual satellite cost and development time. Mass production of the panels is the key to reducing cost and improving reliability, but in the conventional satellite concept, mass production is difficult even at subsystem level due to the wide variety of mission requirements. PETSAT tries to make this possible by modularizing the various basic subsystem functions into standard 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 was the winner of the Best Design Award. Five year research project of PETSAT just started in
Figure 1: Concept of PETSAT before deployment (left) and after (right)

Figure 2: Various shapes realisable by PETSAT

2003, supported by NEDO subsidy, in collaboration of University of Tokyo, Osaka University and manufacturers’ community of Higashi Osaka. In addition to the basic concept development and panel and interface designs, we are pursuing the application of the PETSAT concept to nano-scale thunder observation and remote sensing satellites. In the following sections, first, some technical issues to be solved to realize PETSAT will be described, followed by the results of conceptual study. In particular, the requirements on the panel internal structure and panel interfaces will be discussed in detail, and the first design results to satisfy the requirements will be given.

2. Technical Issues

2.1 Overall Technical Issues

The key technical issues to realize PETSAT include:

1. The question of how to modularize the satellite bus functions into different panels: for example, whether battery and solar panels should be implemented in a separate functional panel such as an electric panel or should be equipped in every panel as standard basic function, etc.

2. Design of a standard panel structure which provides a suitable thermal and structural environment to different kinds of functional panels since for mass production, different types of panels should use the same structure.

3. Interface between panels: four kinds of interface, mechanical, electrical, information, and thermal interfaces should be carefully designed so that the desired plug-in simplicity of PETSAT can be achieved.

2.2 Requirements on Panel Interface

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

1. Mechanical Interface

A panel connection and deployment/latch mechanism, which is very reliable, fault tolerant, soft and highly accurate is required. Also it is required that the panels can be easily plugged-in.
The accuracy of the angles between panels after being latched should be of a sufficient level to allow the initially planned satellite shape to be achieved. Also the latch mechanism should be soft, which means that some mechanism is required to brake the panels’ deployment just before they are latched. Finally, in order to achieve various satellite shapes (see Fig. 2), the sequence of the panel deployment should be carefully designed, otherwise the deployment becomes stacked. Some mechanism is required which assures that, for example, the deployment of panel A and B can be made after panel C is deployed from panel D.

2. Electrical (power) Interface

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 in relation to the power generation and consumption in each panel. Reliability of power lines is another important issue, which should be realized by carefully designed redundancy.

3. Information Interface

Communication between panels is critical 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 microprocessor able to control both this information traffic and manage the information flow inside the panel. So, the total system becomes a multi-processor system where the architecture to manage such large number of CPUs should be carefully designed so that the strengths of a distributed system, such as fault tolerance or capability of grid-computing, can be pursued as much as possible. The information line can be either a wired bus line or an RF line.

4. Thermal Interface

Thermal coupling within and between panels should be made very strong so that the temperature difference between each part of satellite is as small as possible. [1] indicates that this is the best general strategy for thermal control because (1) the thermal environment is different from mission to mission, and (2) there is not much design freedom.
for PETSAT thermal control because the surfaces of panels are almost completely covered with solar cells.

3. Example Missions

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

3.1 Remote Sensing

One potential application is remote sensing. For obtaining high resolution images, the optical system should have long focal length, which requires several mirrors for reflections or a certain distance between a lens and the imaging device such as a CMOS or CCD. Usually several mirrors are utilized for this objective, but high accuracy is required for mirror surfaces, which results in extremely high cost, often with regard to required structural strength. The latter requirement is tough for micro/nano satellites because of size limitations. PETSAT can solve the latter problem through its panel extension mechanism, such as in Fig. 3. Extremely high resolution, such as less than 10 m, is difficult, but a certain level of resolution such as 20 m - 50 m is expected to be achievable with very low cost. Three axis stabilization is required, which is achieved by three attitude control panels, each dealing with stabilization for one axis. In order to obtain well focused images, the accuracy of the angle between panels after deployment is essentially important. However this is very hard to achieve because of the back-rush of the latch or distortion of the panel structure due to temperature change, etc. One method to solve this problem is to control the position and attitude of the image receptor such as CCD or CMOS using very precise actuator. This mechanism is now under development.

3.2 Interferometric Positioning System

If an RF wave arrives at antennae located at different positions on PETSAT, then the difference in arrival time, or phase difference, provides information as to the direction of the RF signal source from the PETSAT. If there are three antennae which are not located collinearly, then the direction of the signal source in 3D space can be estimated. The accuracy of the direction measurement depends on the distance between the antennae (base line) and the knowledge of the relative positions of these
antennae with respect to the satellite body frame. Long base line can be achieved in PETSAT by extension of several panels between the antennae panels, and the relative positions of antennae can be estimated by calibrating this sensor system using a signal generated from a known point on PETSAT.

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

4. Distributing Functions into Panels

In PETSAT, some satellite functions may be implemented as specialized functions of particular panels, and other functions may be implemented as standard functions in all types of panel. Therefore, one of the important research issues is how to distribute various satellite functions into different types of panel. To determine this, the following requirements for PETSAT features should be observed:

(a) Interface simplicity: panels of different types can be plugged-in in any quantity while satisfying the requirements on the four types of interface described in 2.2.

(b) Functions should be improved by increasing the number of panels: for example, the communication capacity should be reinforced.
(c) Standard panel structure: the structures of different panels should be almost the same so that mass production of the panel structure is possible.

(d) Flat 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.

(e) Fault tolerance and graceful degradation: the satellite functions can be maintained at a degraded level in case of failures of certain panels or interface components (such as information lines, power lines, hinges, etc).

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

(a) The variety of panels are as follows: ( ) show

i. OBC Panel (high performance CPU and large memory)
ii. Communication Panel (transmitter, receiver and antenna)
iii. Attitude Control Panel (reaction/momentum wheel/magnetic torquer/gyro: one panel for one axis control)
iv. Orbit Control Panel (thruster, valve, pipes and propellant tank)
v. Battery Panel (large battery)
vi. Mission Panel (different for different missions)

(b) The following components are implemented as standard functions in all types of panel.

i. solar cell and small battery
ii. inter-panel communication-related components
5. Example Designs of Panels and Interfaces

The PETSAT project is now in the initial conceptual study phase, during which the following first step design has been obtained.

5.1 Panel Structure

The panel structure should endure the launch environment. PETSAT is more tolerant against acceleration load because panels are stowed flat during launch. The vibration environment should, however, be considered seriously because the hinges between panels make the structural frequency lower. Another important requirement is that the same standard structure should be used for different types of panels. Considering the required mechanical interface described in 2.2, the main structure and the hinge-part, named link module should be separated as in Fig. 4. The link modules are of several types which can latch the panels at different angles (such as 90, 180, 270°).

Fig. 5 shows one example design of the main structure, which consists of several plates and stiffener (placer between plates). The central plate, termed the mother board, has many holes aligned in a regular grid for attaching components to the panels. Fig. 6 shows one example of the interior design of a panel (for the OBC panel). The Bus Controller and battery are inserted as the standard functions, and CPU and large memory are the Specialized functions. Solar cells are not shown in this figure. In order to improve the heat conductivity within and between the plates, thermal conductors (carbon sheet and Heat Lane Plate) are inserted. Currently the size of the panel is designed as 300 mm by 300 mm with 50 mm height.

5.2 Thermal Design

According to the thermal interface requirements, the temperature difference between panels has been targeted to be less than 5°C. As the solar heat input is usually much larger than the power generated by internal components, the most severe situation, probably yielding the maximum temperature difference between panels, is the case where solar heat is incident on one panel (say, panel P), and the other panel (panel Q), which is 90° bent from panel P doesn’t get any solar heat (Fig. 7). In this case, the 300 mm square panel P gets 135 W of solar heat, which should be transported to the other side of panel P and the neighboring panel Q.

Several heat conducting devices have been examined, and the two candidates, graphite sheet (heat conductivity about 800W/m²K) and small heat pipe named Heat Lane Plate (Fig. 8) are found to be appropriate for heat transfer within and between panels. The Heat Lane Plate is rigid structure and so cannot be used for inter-panel heat transfer. But, it has high heat transport capability (3 × 10⁶ W/m²). If only the graphite sheet is used for the inter-panel heat transfer, the intra-panel temperature difference is so large that it prevents efficient heat transfer between panels. So the Heat Lane Plate is inserted inside the panel to lower the intra-panel temperature difference. Fig. 9 shows the example design of inserting a Heat Lane Plate and graphite sheet inside the panel. The thermal analysis using a simulator indicated that with these heat conducting devices, the intra- and inter-panel temperature difference can be less than 5°C. Fig. 10 shows the thermal simulator results for a simple model of two panels connected as in Fig. 7. It was shown that the temperature difference within one panel is less than 5°C and the difference between the two panels at the connecting point can be suppressed under 5°C.

5.3 Information Infrastructure

Firstly, the question of which of the two candidates for information lines, wired bus or RF LAN, should be employed has been studied, taking the interface requirements into account. Though RF LAN is superior in that no wiring is required, and so it is more tolerant to panel failure, the possible interaction between RF LAN and PETSAT-ground RF communication and the relatively large power required makes the usage of wired bus more attractive. With regard to the wired bus system, CAN bus is promising as it is capable of relatively high speed (1Mbps) and has already been used in many areas, so that there exists much supporting software/hardware for development of CAN bus system. Currently an information system using CAN bus and an SH-series bus controller is being developed.

6. Conclusions

A novel satellite concept of PETSAT is proposed, and its features, applications and basic design philosophy have been described. In order to further space development activities, satellite design philosophy needs an essential breakthrough so that reliable and capable satellites can be
fabricated within a shorter period and at far lower cost. PETSAT can be said to be one trial to approach such a breakthrough.

Acknowledgements

PETSAT research project is supported by NEDO subsidy.

Bibliography