3 Development of Satellite System

3-1 Overview of ETS-VIII Satellite

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Engineering Test Satellite VIII (ETS-VIII) has purposes of establishing 3-ton-class geostationary satellite bus technology in the world class, equipped with large deployable reflectors, answering to the emerging demands in mobile communications and global positioning necessary for the early 21-st century, and conducting the relevant experiments on orbit. ETS-VIII satellite bus incorporates NASDA-developed technologies such as reduced-weight modular body structures, 7.5 kw-class high power supply in 100 volts, multipurpose 1553B data bus and CCSDS-based packet transmission, attitude stabilization for the satellite with large flexible structures, unified satellite controller of 64-bit MPU with reprogramming capability.

Keywords
ETS-VIII, 3-ton-class geostationary satellite bus, Large deployable reflector

1 Introduction

The Engineering Test Satellite VIII (ETS-VIII) [1] has been designed to inherit the satellite technologies accumulated in the development of the Engineering Test Satellite VI (ETS-VI), the Communications and Broadcasting Engineering Test Satellite (COMETS), the Data Relay Test Satellite (DRTS), and others. Its purpose will be to further technological development and provide a platform for the experiments described below, contributing to the establishment of the advanced common fundamental technologies and satellite communications technologies required for future space activities. A diagram of the ETS-VIII in orbit is shown in Fig.1, and its main specifications are provided in Table 1.

- A three-ton-class geostationary satellite featuring the world's most advanced bus technology, designed to support a variety of cutting-edge space applications
- World's largest and most advanced large deployable reflector (LDR; maximum outer diameter: 19 m × 17 m)
- Mobile communications system for geostationary satellites capable of voice and data communications with portable terminals
- Mobile satellite digital multimedia broadcasting enabling transmission of voice and images of high quality comparable to that of compact disc (CD) media
- Essential positioning technologies including highly precise time reference devices

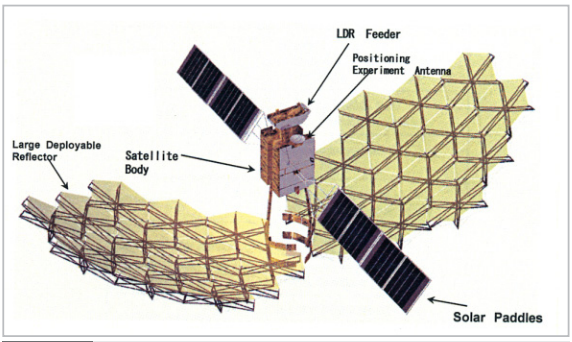

Fig.1 *Diagram of the Engineering Test Satellite (ETS-VIII) in orbit*

Table 1 *Main specifications of the Engineering Test Satellite (ETS-VIII)*

Item	Characteristics
Launch Year	JFY2004 Launched by H-IIA204 at Tanegashima Space Center
Design Life	10 years (Satellite Bus) 3 years (Mission Equipment)
Orbit	Geostationary orbit (146° East)
Weight	3,000kg (at beginning of life) 1,200kg (mission equipment)
Electric Power generated	7,500W (summer solstice, 3 years after launch)
Attitude Control	3-Axis Stabilized
Attitude Accuracy	±0.05° (Roll/Pitch) ±0.15° (Yaw)
Antenna Pointing	Overall accuracy: within 1°

The National Space Development Agency of Japan [NASDA; consolidated as of October 1, 2003 (Heisei 15) with the Institute of Space and Astronautical Science (ISAS) and the National Aerospace Laboratory of Japan (NAL) to form the Japan Aerospace Exploration Agency (JAXA)] is developing the ETS-VIII together with the Communications Research Laboratory (CRL), the Nippon Telegraph and Telephone Corporation (NTT), and the Advanced Space Communications Research Laboratory (ASC). NASDA's geostationary satellite bus carries a payload that includes NASDA's large deployable reflector (the first of its kind to be deployed, a 400-W high-output phased array feeder section (ASC, CRL, NTT), a transponder section (ASC), an on-board switchboard section for mobile communications (ASC, CRL), a highly precise time reference device (NASDA, CRL), and a feeder link device (NASDA), among other items. Fig.2 shows the system configuration of the ETS-VIII in detail. Fig.3 shows a scene of the assembly of the ETS-VIII flight model (August 2003).

Throughout the system design of the ETS-VIII, a redundant configuration is adopted for each item of equipment. In terms of those items that cannot feature a redundant configu-

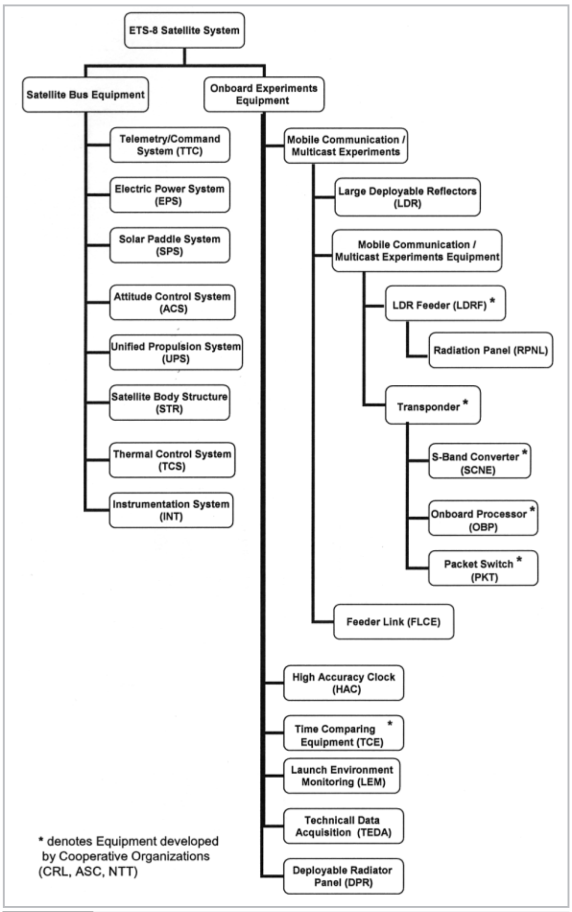

Fig.2 *System configuration of ETS-VIII*

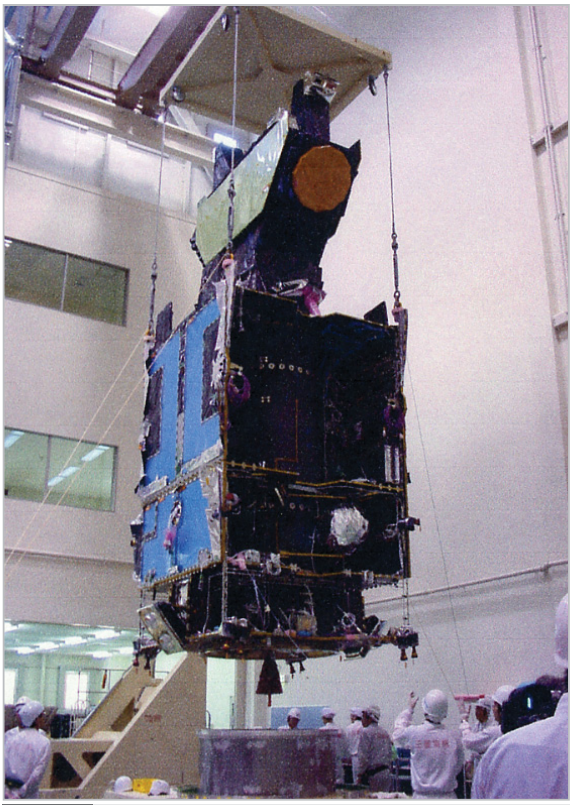

Fig.3 *Assembly of ETS-VIII flight model (August 2003)*

ration in terms of their functions (referred to as “single-point” components, including the antenna, apogee engine, power supply bus line, etc.), each such single-point component is provided with an alternate function so that overall system functioning may be maintained in case of a fault.

A flight model of the ETS-VIII has already been manufactured and assembled, and has been undergoing integrated system testing since this summer (2003), with development to be complete next spring (2004). Fig.4 shows the development schedule for the ETS-VIII.

The ETS-VIII is to be launched by the H-IIA204 rocket from the Tanegashima Space Center at the end of 2004. Fig.5 shows the sequence of system operations for the ETS-VIII.

2 ETS-VIII bus system

The payload mass required for the ETS-VIII to accomplish its mission is as high as approximately 1.2 tons, involving power consumption (including the bus) of about 7 kW. The payload mass of the two-ton-class geostationary ETS-VI and COMETS satellites was approximately 600 kg and the generated power was about 4 to 5 kW; since the ETS-

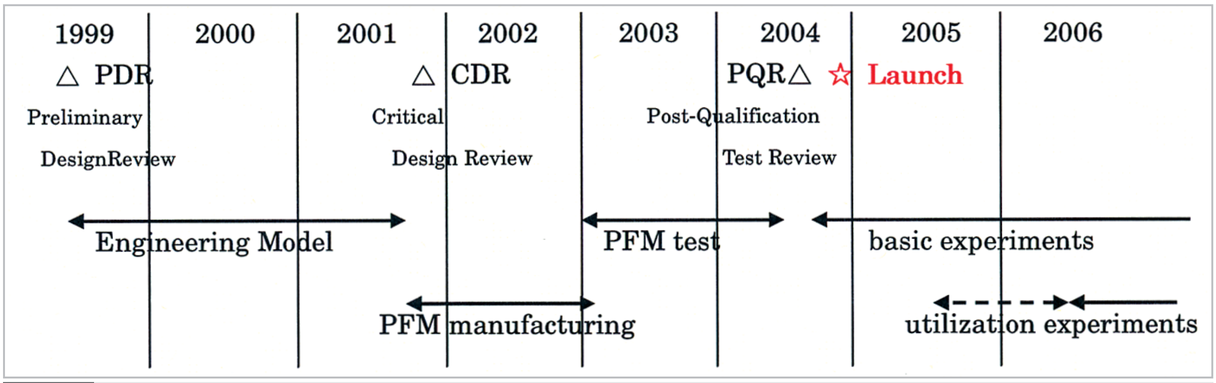

Fig.4 *Development schedule of the ETS-VIII*

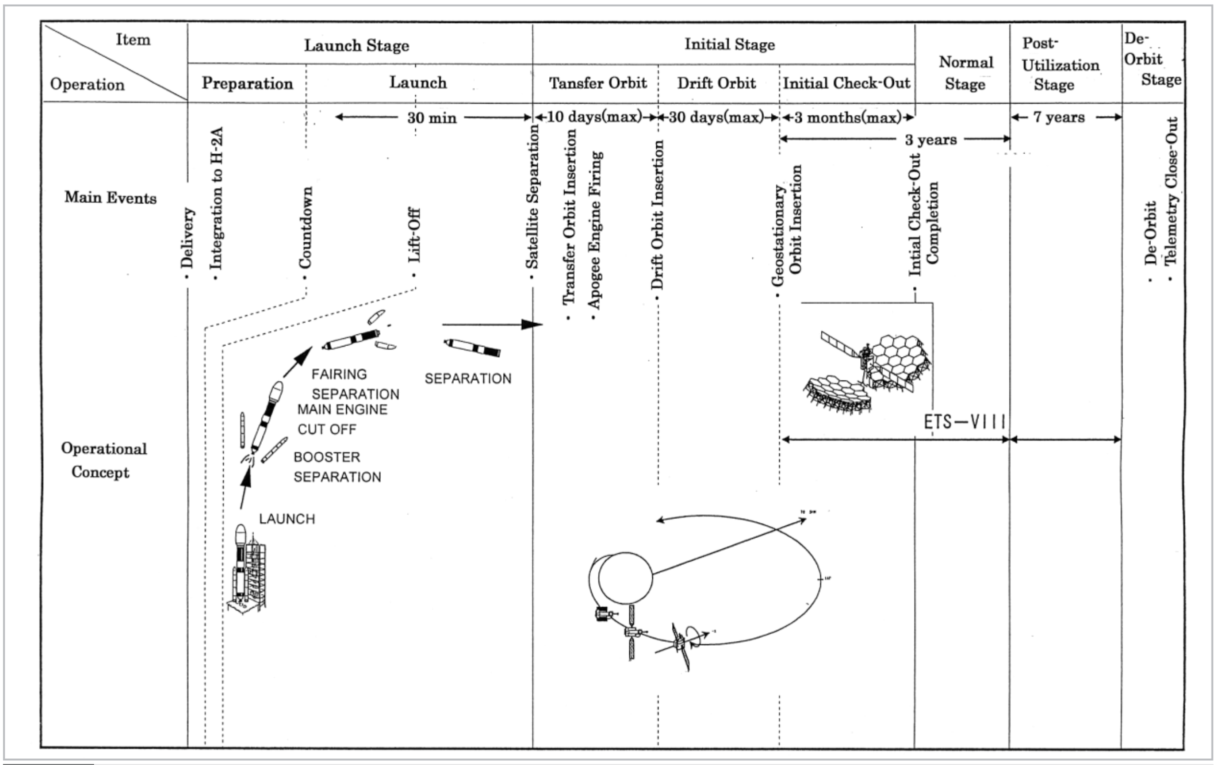

Fig.5 *Sequence of system operations of the ETS-VIII*

VIII requires greater capacity, we began development of a three-ton-class geostationary satellite bus for the ETS-VIII. In addition, in the overseas, demands for large capacity and advanced communications and broadcasting functions have increased. As a result, overall enlargement, increased power supply, longer service life, and increased payload ratio are required, leading to the promotion of the three-ton-class geostationary satellite bus. Accordingly for the ETS-VIII a three-ton-class geostationary satellite has been designed to take flexibility and expandability (in terms of mass, electric power, etc.) into account. Fig.6 shows a functional system diagram of the ETS-VIII bus equipment, while Fig.7

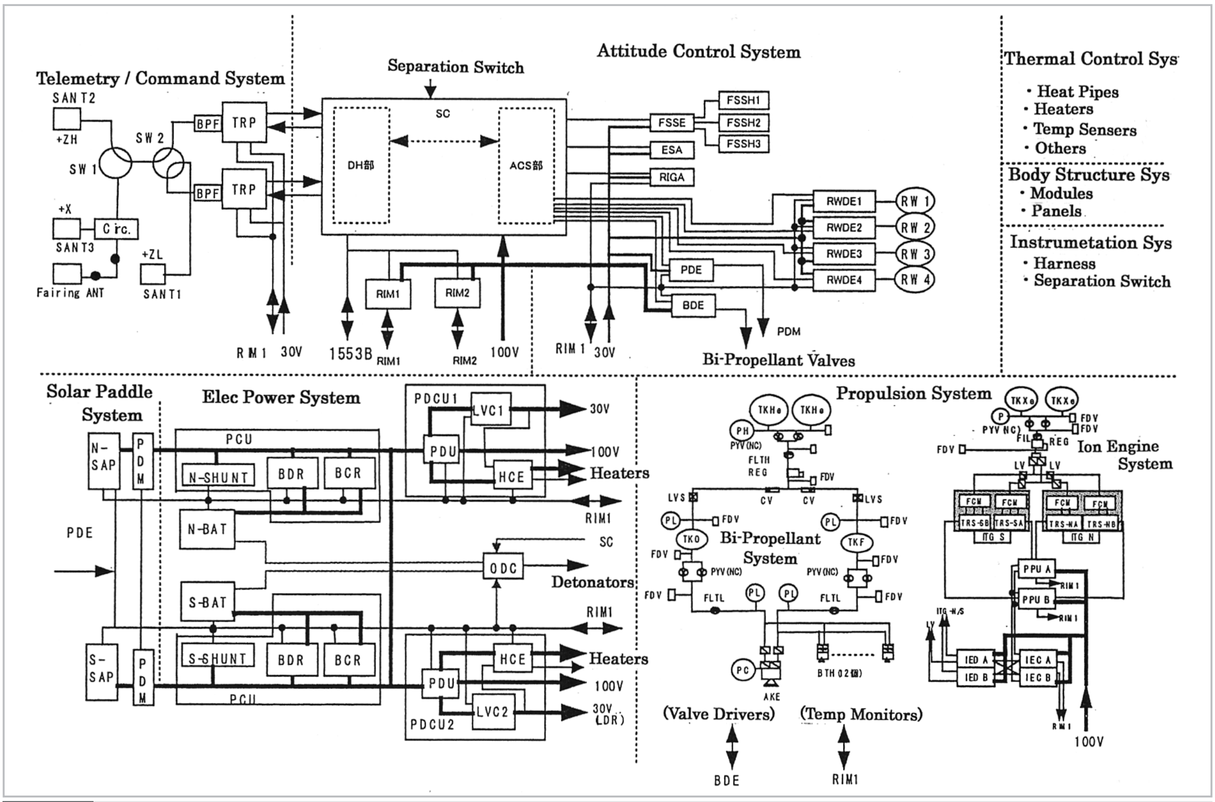

Fig.6 *ETS-VIII functional system diagram (bus equipment)*

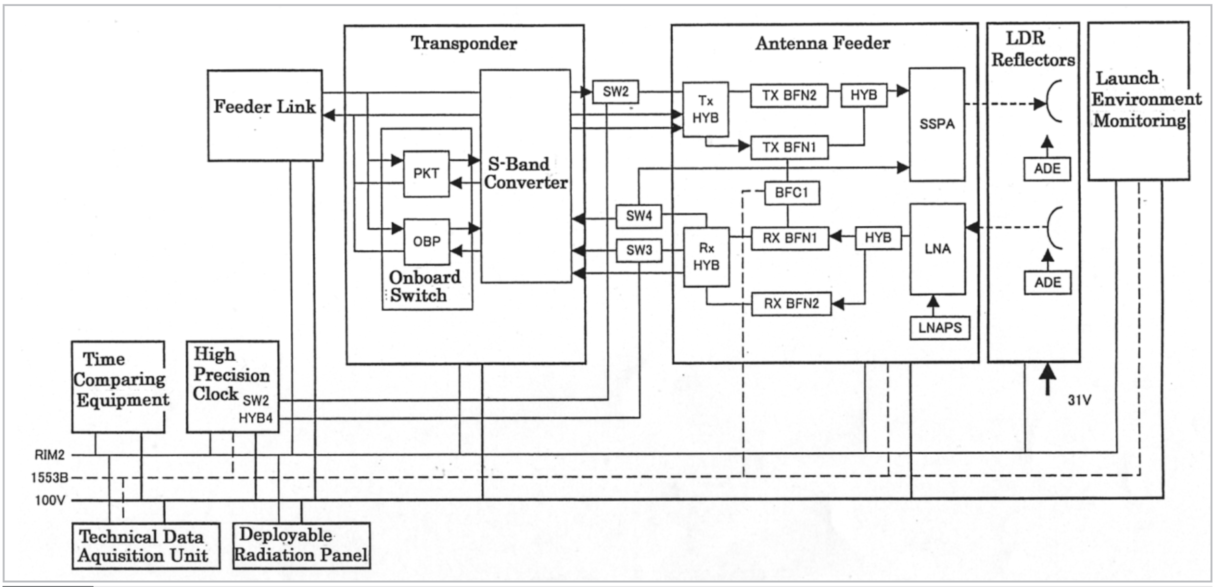

Fig.7 *ETS-VIII functional system diagram (on-board experimental equipment)*

shows a functional system diagram of the ETS-VIII on-board experimental equipment. The main technologies developed in connection with the ETS-VIII three-ton-class large satellite bus are described below.

- Supports a three-ton-class bus. Improvement in payload capacity, with a payload weight ratio (an index of satellite bus technology) of 40% (traditionally 30%).
- Large lightweight modular body structure resulting in a shorter development schedule (the assembly realized through modularization)
- Power supply may be increased thanks to advanced heat-exhaust technology (enlargement of effective radiating surface by a north-south connecting heat pipe)
- Data-handling technology enabling improved system generality, expandability, and operability (system is generalized with a 1553B data bus, and international compatibility is ensured through CCSDS-compliant packet transmission), as well as improved automation and a reduction in the number of components
- Highly stable, highly precise attitude control for a satellite having large flexible structures (two sheets of large deployable reflectors and two paddle wings consisting of large solar cells)
- Integration of attitude control, data processing, and satellite management functions into a satellite controller (equipped with a 64-bit MPU)
- Addition of a fault-tolerant function and a re-programming function that allows re-writing of loaded software from the ground

Focusing on these main technological developments, the subsystem design of the ETS-VIII satellite bus is described below.

2.1 Telemetry command system

As a data transmission system for telemetry commands (i.e., a multiplexing system), the ETS-VIII employs a packet transmission system compliant with CCSDS (Consultative Committee for Space Data System) recommendations, using USB (United S-Band) technology. The features of this system are as follows.

- Compatibility with future international standards, evidenced by its adoption by NASA and ESA
- Flexible output formats and output frequencies
- Sophisticated error correction allowing transmission of large amounts of data, images, software, etc.
- Permits interface adjustment with onboard satellite subsystem

The CCSDS packet system inherited the achievements of the ETS-VII, and is further miniaturized and sophisticated in the ETS-VIII. An on-board CCSDS processing device has been realized in an LSI. As data bus systems, the ETS-VIII employs the MIL-STD-1553B data bus, a virtually international multipurpose standard interface, and features expandability beyond the conventional system of establishing connections via a remote interface unit (RIU). The adoption of the 1553B renders it possible to establish a direct connection between the on-board equipment and the data bus and provides an interface for telemetry commands with variable-length packets, which increases the degree of freedom in data transmission from on-board equipment.

2.2 Power supply system

The power supply system for the ETS-VIII employs a 100-V regulated power supply bus. Although NASDA satellites after the ETS-VI used 50-V brute supply busses, a 100-V regulated power supply bus was selected for the ETS-VIII based on the anticipated required power supply (more than 6 kW) and the requirement that the system be upgradeable to provide higher power (10 to 15 kW), a feature considered necessary for future satellite applications. Among the various advantages of the 100-V regulated power supply bus, the power efficiency of the overall system is increased through a reduction in power transfer loss. In terms of the ETS-VIII, the difference between a 100-V regulated power supply bus and a 50-V brute supply bus translates into a power difference of 400 to 500 W. In addition, the 100-V regulated power supply bus provides the following further advantages.

- Reduced system mass and improved system reliability through a 50% reduction in the number of harnesses
- Reduced solar-cell panel area (a reduction equivalent to 70% of a single panel) and paddle mass
- Mitigation of attitude disturbance, through a reduction in loaded propellant attributable to the reduced solar-cell panel area
- High degree of freedom in the selection of battery stages; future expandability to higher power

On the other hand, the change in voltage from 50 V to 100 V entails special consideration in design to discharge measures and the selection of parts. To address these points, we intend to design and implement ample discharge measures and are verifying selected parts through component experiments. A 100-AH NiH_2 battery has been adopted, developed based on the 50-AH nickel hydrogen (NiH_2) battery aboard the DRTS.

2.3 Solar-cell paddle system

Solar-cell paddles consist two wings, north and south, each measuring 13.5 m × 2.5 m, comprised of a total of four panels, which rotate to follow the sun, generating 7,500 W of power (predicted for summer solstice after three years of operation). For these solar-cell paddles, a lightweight rigid system is adopted; this system will be less affected by the increase in mass accompanying future wider paddles (to accommodate increased power supply) and is also relatively cost-competitive. This system uses a rigid aluminum honeycomb panel featuring a highly elastic carbon fiber reinforced plastic (CFRP) surface, offering reduced thickness and high stiffness; therefore, a comparatively rough material can be used for the cells of the honeycomb core, leading to a lighter paddle. A highly efficient Si solar cell (Si-NRS/BSF) was selected, taking weight reduction, miniaturization, and cost into consideration. As a concrete measure against dielectric breakdown accompanying the voltage increase to 100 V, a number of measures were implemented in the design of the solar cell, including reduction in the potential difference between adjacent cell arrays and embedding of insulation in the gaps between adjacent cell arrays.

2.4 Attitude control system

The ETS-VIII employs an attitude control system developed based on the COMETS and DRTS systems [2]. Such a system stabilizes attitude using a gyroscope as a reference; it updates roll angle and pitch angle using an Earth sensor, and adjusts yaw angle using a fine-tuned Sun sensor. Disturbance by solar radiation pressure acting upon the large deployable reflector of the ETS-VIII is approximately thirty times that seen in conventional satellites. Therefore, the zero-momentum method is adopted for the attitude stabilization system; four large-capacity 50-Nms reaction wheels absorb the disturbance in a four-skew arrangement, and the absorbed disturbance is unloaded (removed) by thruster jet. However, in preparation for potential malfunctioning of the on-board gyroscope, the system is capable of control by the bias-momentum method, through estimation of the external disturbance or other means. Since it is difficult to conduct an overall structural test of the large deployable reflector on the ground, it is anticipated that a certain degree of indeterminacy will be included in the specifications of the flexible structures to be used for attitude control. Therefore, the ETS-VIII is designed to mitigate calculation delay through high-speed operations of the satellite controller (SC), to permit the control bandwidth to be set as wide as possible, to stabilize phase, and to render the SC adaptable to variations in the specifications. Moreover, the system identifies the mode frequencies of the flexible structures in orbit (a total of 13 accelerometers are mounted on the satellite to acquire the necessary data), allowing the control system to be tuned using the re-programming function of the SC.

2.5 Modular body structure

The ETS-VIII modular body structure is based on a central cylinder composed of an antenna tower (the “rooftop”) carrying an antenna power supply, a payload module (upper stage) carrying onboard experimental equipment, a bus module (middle stage) carrying bus equipment, and a propulsion module (lower stage) carrying a subsystem of the propulsion system. In the central cylinder, the fuel tank and oxidizer tank are arranged vertically. The construction of the modular body structure system is shown in Fig.8. The modular body structure will support the ETS-VIII’s launching mass of 5.8 tons and is capable of supporting up to 6 tons without alteration of the design. Moreover, its payload capacity is 40%, as compared to the 30% figure for the ETS-VI and COMETS two-ton-class satellites. The mass of the modular body structure is less than 340 kg, due to the weight reduction provided through the use of CFRP, and to reductions in the number of materials, parts, joints, and the like. Since the payload module and the bus module are partitioned by web-panels on the north and south planes, the interiors of these modules can be easily accessed by removing the access panels on the east and west sides. Moreover, since the modular satellite body can be mounted on a dual-axis rotational dolly, accessibility to internal on-board equipment and external on-board equipment is ensured—the entire modular satellite body can be made to rotate. Furthermore, assembly, disassembly, and testing can be executed in parallel for each module, so that work can be performed efficiently in a short period of time.

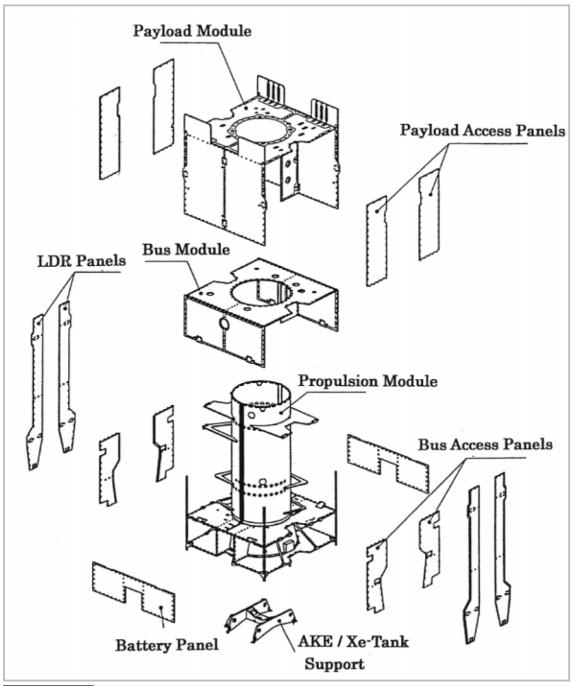

Fig.8 *Construction of ETS-VIII modular body structure*

2.6 Thermal control system

A time-proven combination active/passive thermal control system is employed to control the on-board equipment to ensure that a margin of 15℃ or more is ensured with respect to allowable temperatures throughout the entire mission period. The thermal control system of the ETS-VIII features a north-south connecting heat pipe panel of CFRP surface for an Earth panel of the payload module. This results in high-capacity heat exhaust, which in turn increases power supply in future satellites, reduces limitations on the placement of heat-generating equipment, and allows for effective use of the Earth panel. The system provides automated thermal control using an on-board computer: temperature is read from sensors mounted on the modular satellite body, and the heater is automatically turned on and off aboard the satellite. This reduces the amount of required ground operations, permits thermal control to be reset in orbit, and enables fine temperature control in operation). The north-south connecting heat pipe is embedded in the Earth panel, allowing for equalization of heat between areas exposed to sunlight and those in shade, or between areas with more heat-generating equipment and those with less, through thermal connection of the south and north planes. Overall heat exhaust is improved as a result.

Furthermore, plating the payload module with CFRP surfaces (featuring improved thermal conductivity) provides greater strength, higher rigidity, and lower thermally-induced-distortion, leading to more stable orbital alignment than available using conventional aluminum surface. The ETS-VIII also carries a deployable radiator for use in orbital experiments, and can deploy radiating paddles in space to verify its own operating characteristics and heat-exhaust capacity.

2.7 Propulsion system

The propulsion system of the ETS-VIII is made up of a 500-N dual-liquid apogee engine (AKE) for geostationary orbit launch, 20-N dual-liquid thrusters for attitude control and east-west orbit control, and 20-mN xenon (Xe) ion engine devices for north-south orbital control. The four separate firings of the apogee engine together transfer the satellite into a geostationary orbit. The number of thrusters for attitude control and east-west orbital control has been reduced from the 20, mounted in each of the ETS-VI and COMETS satellites, to a total of 12 thrusters. The apogee engine and the thrusters for attitude control and east-west orbital control share a fuel tank and an oxidizer tank. For east-west orbital control, two thrusters are activated simultaneously.

For north-south orbital control, the two ion engines are activated in an ascending node and in a descending node, respectively. The ion engine has been improved to provide greater service life, a simplified structure, and easier operation, based on the achievements of the ETS-VI and COMETS. The thruster mounting positions have been changed from the east/west arrangement seen on the ETS-VI and COMETS satellites to a north/south orientation on the anti-Earth plane. Additionally, simultaneous dual-thruster operation has been changed to separate single-thruster operation (to reduce peak power), and a gimbal mechanism has been added to enable adjustment of the propulsion vector.

2.8 Integrated design

The ETS-VIII integrates the following three tasks using the satellite controller (SC) through time-division processing: data processing in the telemetry command system, high-speed calculation in the attitude control system, and satellite management (e.g., heater control and battery management). The advantages of integration include enriched FDIR (Fault Detection, Isolation and Reconfiguration) and enhanced re-programming functions, in addition to a reduced number of onboard components and increased flexibility in satellite operations. A 64-bit MPU newly designed by NASDA for space applications is used in the computer of the SC.

The MPU periodically diagnoses data from sensors, actuators, and other components of the attitude control system as part of its FDIR functions. If a fault is detected, the MPU isolates and assesses the failed part and takes appropriate actions, such as switching to a redundant system, using the SC's automatic processing functions. Automatic processing of a failure is performed in three phases, corresponding to the broad division of faults into the following three levels. In Level 1, the SC is normal, and the failed part is automatically re-configured through isolation and switchover to the redundant system, without the need to recover attitude; in Level 2, the SC is abnormal, and the recovery of attitude becomes necessary in addition to switching from the failed part to the redundant system; and in Level 3, the failed part presents a fault that cannot be dealt with by SC switching or a fault that causes recovery of attitude to fail, so the SC immediately moves into sun acquisition mode to secure power and waits for commands from the ground. To prepare for a fault that cannot be resolved by FDIR functions, the SC is provided with a re-programming function. The re-programming program, designed and verified on the ground, is transmitted using a magnitude command, written in the RAM reprogram area (approx. 128 KB) of the SC, and executed.

3 Onboard experimental equipment

A functional system diagram of the ETS-VIII onboard experimental equipment is shown in Fig.7.

The large deployable reflector (LDR) is an antenna for S-band mobile communications and multicasting experiments, and is composed of two antenna planes, each of which is capable of transmission and reception. One antenna plane is composed of 14 hexagonal modules, and measures 19 m × 17 m in outer dimensions; this is the largest antenna of its kind. The satellite is launched into a geostationary orbit with its LDR retracted, and the LDR is then deployed to its final configuration. Since this deployment is a critical event and involves innovative techniques, we intend to develop the antenna and the related technology empirically, through deployment analysis, launch-environment tests, micro-gravity experiments, and more throughout all phases of design, manufacture, and testing [3].

The feeder link communications equipment (FLCE) relays (i.e., receives and transmits) signals between a ground base station and mobile communications equipment (an S-band converter, an on-board processor, and a packet switchboard) in the Ka band through the FL antenna, enabling experiments in mobile communications and multicasting.

The high accuracy clock (HAC), based on a cesium atomic clock, generates a time reference, enables execution of positioning experiments in the S-band and the L-band (using the HAC antenna in combination with GPS data), and provides the fundamental technology for geostationary satellite positioning. Moreover, the HAC features an interface for mobile communications equipment, and is capable of transmitting and receiving signals in mobile communications and multicasting experiments, thus serving as a backup for the S-band system in the event of abnormalities in the LDR.

4 Concluding remarks

To ensure that we will be able to pursue future space activities, including those related to mobile communications and global positioning, it is indispensable that we develop a large deployable reflector and at the same time establish the technology for a large lightweight bus with a high payload capacity. The ETS-VIII offers increased communication capacity, payload ratio, power supply capability, and service life, based on development of a large, world-class geostationary satellite bus offering sufficient flexibility to support three-ton-class satellites.

Acknowledgements

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References

1 K. Yonezawa, M. Homma, S. Yoshimoto, S. Hama, T. Ohira, N. Natori, and Y. Tsutsumi, "Outline of Engineering Test Satellite-VIII (ETS-VIII)", ISTS 98-h-01V, 21th International Symposium on Space Technology and Science, 1998.

2 K. Yonezawa and M. Homma, "Attitude Control on ETS-VIII Mobile Communication Satellite with Large Deployable Antennas," 21st AIAA/ICSSC, Yokohama, April 2003, Paper # AIAA-2003-2216.

3 H. Homma, S. Hama, H. Kohata, M. Hamamoto, and M. Tanaka, "Experiment Plan of ETS-8 in Orbit: Mobile Commnications and Navigation," Acta Astroautica 53 ,477-484, 2003.

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