

# Project of Osaka Institute of Technology Electric-Rocket-Engine onboard Small Space Ship

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**Abstract:** In the Project of Osaka Institute of Technology Electric-Rocket-Engine onboard Small Space Ship, a small satellite with electrothermal pulsed plasma thrusters (PPTs) will be launched in 2010. The main mission is to achieve powered flight of small satellite by an electric thruster and to observe Kansai district in Japan with a high-resolution camera. We developed Bread Board Model (BBM) and Engineering Model (EM) of the satellite, including electrothermal PPT system, high-resolution camera system, onboard computer system, communication system and ground station, electric power system, attitude control system etc, in 2007-2008. PROITERES is successfully under way.

## I. Introduction

THE Project of Osaka Institute of Technology Electric-Rocket-Engine onboard Small Space Ship (PROITERES), as shown in Figure 1, was started at Osaka Institute of Technology in 2007.<sup>1-3</sup> In PROITERES, a small satellite with electrothermal pulsed plasma thrusters (PPTs) will be launched in 2010. The main mission is to achieve powered flight of small satellite by an electric thruster and to observe Kansai district in Japan with a high-resolution camera. The raising in Sun Synchronous Orbit will be carried out by the PPTs.

Our satellite R&D groups are divided into eight sections. We take a student member meeting one time a week and examine the satellite system. Each section developed Bread Board Model (BBM) and Engineering Model (EM) of the satellite in 2007-2008. In this paper, we introduce the recent progress of PROITERES.

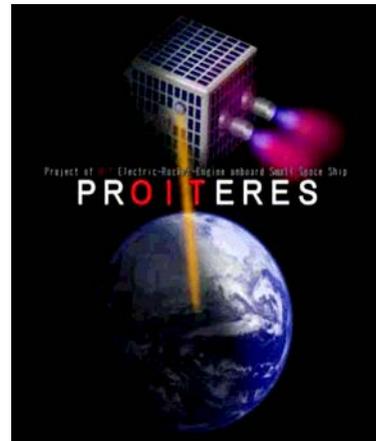


Figure 1. Illustration of powered flight of Osaka Institute of Technology small space ship by electric rocket engine.

## II. “PROITERES” Satellite Overview

The specification of the satellite, as shown in Table 1 and Figure 2, is as follows. The weight is 10 kg; the configuration is a 0.3 m cube; and the minimum electric power is 10 W. The altitude is 600-800 km in Sun

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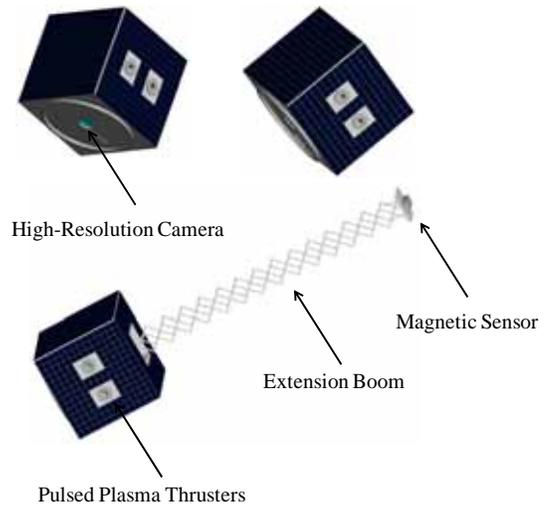
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Synchronous Orbit. The lifetime is above one year. The launching rocket is PSLV in India, and the time will be Spring of 2010.

**Table 1. Specification of satellite**

Specifications	Value
Mass	10kg
Dimensions	Cube , 300mm on a side
Electrical power	10W
Altitude	600~800km
Development period	3year
Age	More than one year
Orbit	Sun-synchronous orbit
Rocket booster	PSLV
Mission	1) Powered flight by electric rocket engine.
	2) Observation of Kansai district in Japan with a high-resolution camera.



**Figure 2. Image of PROITERES.**

### III. Mission and Their System

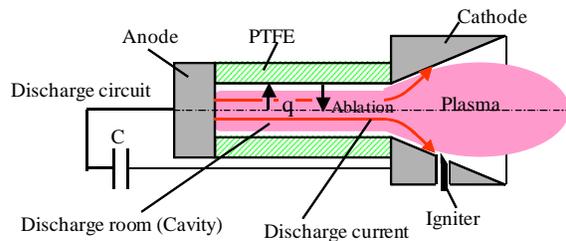
#### A. Powered flight by electric thruster

Pulsed plasma thrusters, as shown in Figure 3, are expected to be used as a thruster for a small satellite. The PPT has some features superior to other kinds of electric propulsion. It has no sealing part, simple structure and high reliability, which are benefits of using a solid propellant, mainly Teflon® (poly-tetrafluoroethylene: PTFE). However, performances of PPTs are generally low compared with other electric thrusters.

At Osaka Institute of Technology, the PPT has been studied since 2003 in order to understand physical phenomena and improve thrust performances with both experiments and numerical simulations.<sup>2</sup> We mainly studied electrothermal-acceleration-type PPTs, which generally had higher thrust-to-power ratios (impulse bit per unit initial energy stored in capacitors) and higher thrust efficiencies than electromagnetic-acceleration-type PPTs. Although the electrothermal PPT has lower specific impulse than the electromagnetic PPT, the low specific impulse is not a significant problem as long as the PPT uses solid propellant, because there is no tank nor valve for liquid or gas propellant which would be a large weight proportion of a thruster system.

In our study, the length and diameter of a Teflon discharge room of electrothermal PPTs were changed to find the optimum configuration of PPT heads in very low energy operations for PROITERES satellite. Initial impulse bit measurements were conducted, and long operations and endurance tests were also carried out with the optimum PPT configuration.

Figure 4 shows a thrust stand in a vacuum chamber for precise measurement of an impulse bit. The PPT and capacitors are mounted on the pendulum, which rotates around fulcrums of two knife edges without friction. The



**Figure 3. Pulsed plasma thrusters.**

**Table 2. Experimental conditions of endurance test.**

<b>Capacitor, <math>\mu\text{F}</math></b>		<b>1.5</b>
<b>Charging voltage, V</b>		<b>1800</b>
<b>Stored energy, J</b>		<b>2.43</b>
<b>Cavity</b>	<b>Length, mm</b>	<b>9.0</b>
	<b>Diameter, mm</b>	<b>1.0</b>
<b>Nozzle</b>	<b>Length, mm</b>	<b>23</b>
	<b>Half angle, degree</b>	<b>20</b>

displacement of the pendulum is detected by an eddy-current-type gap sensor (non-contacting micro-displacement meter) near the PPT, which resolution is about  $\pm 0.5 \mu\text{m}$ . Figure 5 shows a vacuum chamber 1.25 m in length and 0.6 m in inner diameter, which is evacuated using a turbo-molecular pump with a pumping speed of 3,000 l/s. The pressure is kept below  $1.0 \times 10^{-2}$  Pa during PPT operation. We carried out endurance tests with the optimum cavity shape 9.0 mm in length and 1.0 mm in diameter at a discharge energy per one shot of 2.43 J/s. Table 2 shows the operational condition of endurance test. The repetitive frequency is 1.0 Hz.

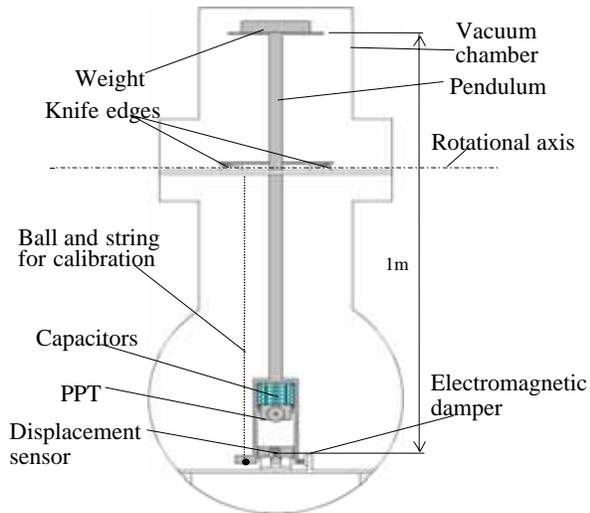


Figure 4. Thrust stand.



Figure 5. Vacuum chamber.

Figure 6 shows the shot-number history of impulse bit, mass loss, specific impulse and thrust efficiency. Both the impulse bit and the mass loss, as shown in Figure 6(a), rapidly decrease with increasing shot number. Specially, the impulse bit decreases from 250  $\mu\text{Ns}$  at initial condition to 75  $\mu\text{Ns}$  after about 50,000 shots. Although a few miss fires occurred around 53,000-shot, a total impulse of about 5 Ns was achieved. As shown in Fig. 6(b), the specific impulse increases with increasing shot number, and the thrust efficiency is around 0.2 during the repetitive operation. The cavity diameter, as shown in Figure 7, increases from 1.0 mm to about 6.0 mm of the anode diameter after 50,000 shots. The discharge feature, as shown in Figure 8, changes from a long plasma plume with intensive emission light at 1-10,000 shots to a very short plume with weak emission. This is expected because of lowering pressure and ionization degree in the cavity when enlarging cavity diameter.

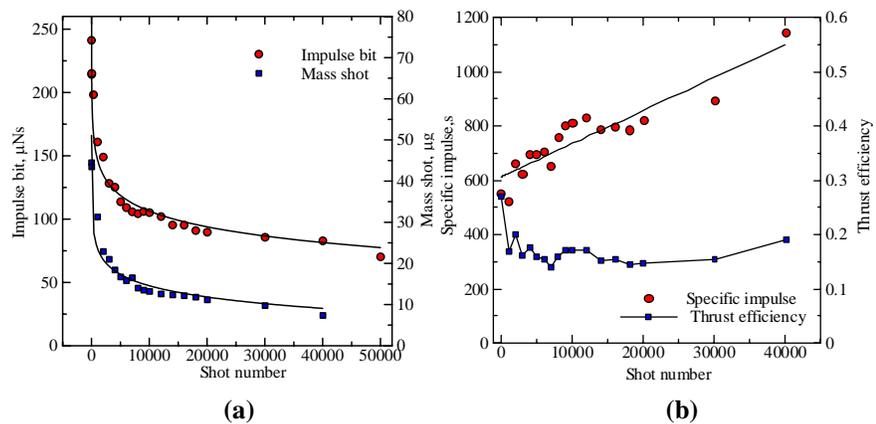


Figure 6. Result of endurance test.  
a) Impulse bit and mass shot, b) specific impulse and thrust efficiency.

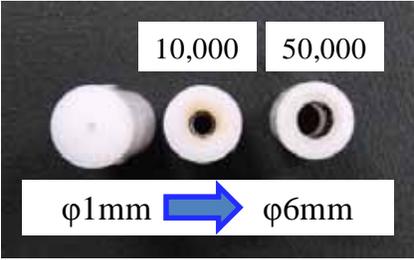


Figure 7. Change of cavity diameter before and after 50,000-shots.

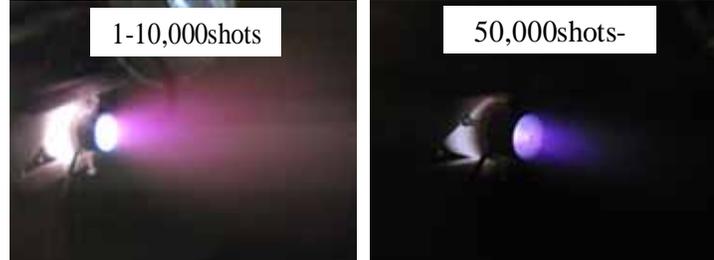


Figure 8. Features of plasma plume a) 1-10,000 shots, b)50,000shots.

We designed the engineering model of a PPT head and its system. Figures 9 and 10 show the structure, illustrations, and photos. The PPT head has a simple structure, and two PPT heads are settled on the outer plate of PROITERES satellite. As shown in Figure 10(d), the power processing unit and the 1.5- $\mu$ F capacitor are mounted in the satellite. The PPT system is under operation as final test.

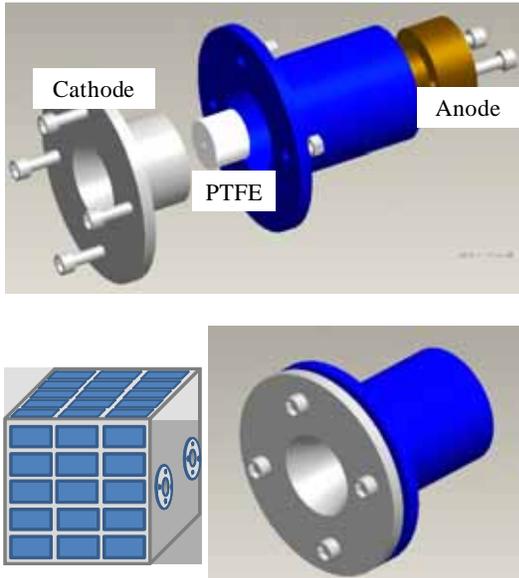


Figure 9. a) Structure and b) illustrations of engineering model of PPT.

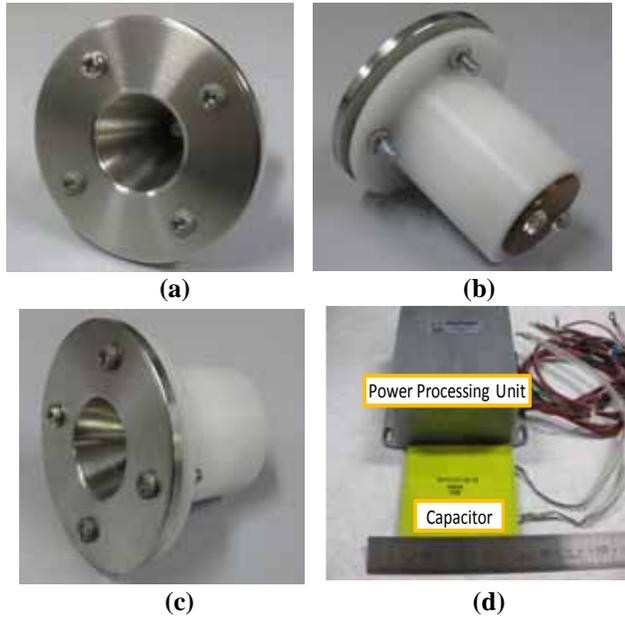


Figure 10. (a),(b),(c) Photos of PPT head and (d) power processing unit and 1.5- $\mu$ F capacitor of engineering model of PPT.

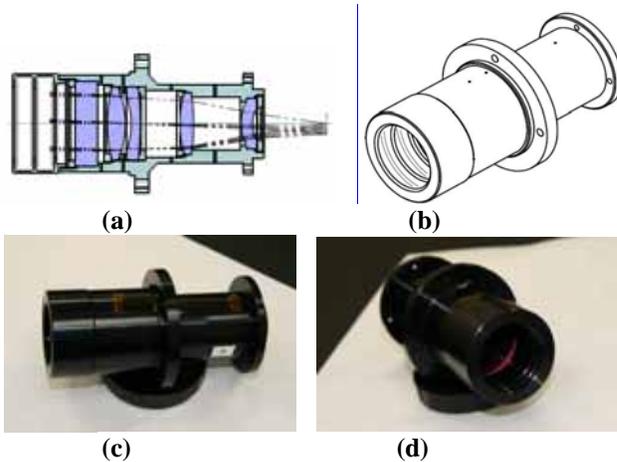
### B. Observation of Kansai district

A high-resolution camera system is being developed for PROITERES satellite. Figures 11 and 12, and Table 3 show the engineering model of the optical system, the CMOS sensor, and the specification. The optical system has five-lens system with a focal length of 85.3 mm and a F number of 3.6. The mass is 230 g, and the length and diameter are 109 mm and about 50 mm, respectively. Accordingly, the optical resolution is

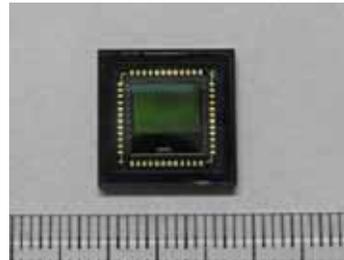
Table 3. Engineering model of the optical system.

Parameter	Typical Value
Model number	MT9T001
Size	14.22mm×14.22mm
Active imager size	6.55mm(H)×4.92mm(V) 8.19mm(Diagonal)
Active pixels	2048H×1536V 3-Megapixel
Pixel size	3.2 $\mu$ m×3.2 $\mu$ m

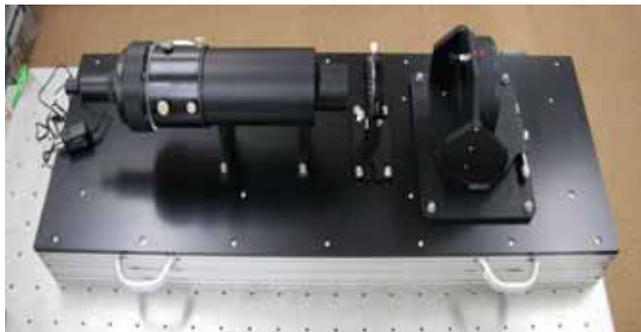
30 mm for the CMOS sensor. After accurate alignment between the optical system and the CMOS sensor with a special facility shown in Figure 13, the camera system will be onboard the satellite. As shown in Figure 14, we will be able to observe the Kansai district with Yodo River from PROITERES satellite.



**Figure 11. (a) Cross-sectional drawing of optical system,(b) Outline view of optical system,(c) Side view of optical system,(d) Front view of optical system.**



**Figure 12. CMOS sensor.**



**Figure 13. Alignment device.**



**Figure 14. Photography image of Kansai district**

#### **IV. Satellite System R&D**

##### **C. Structure**

Figure 15 shows the engineering flight model of the satellite structure under ANSYS analysis. Main satellite frames and walls are made of duralumin A7075. Both a mass dummy and the engineering model of the satellite were safe under all vibration tests required from India.

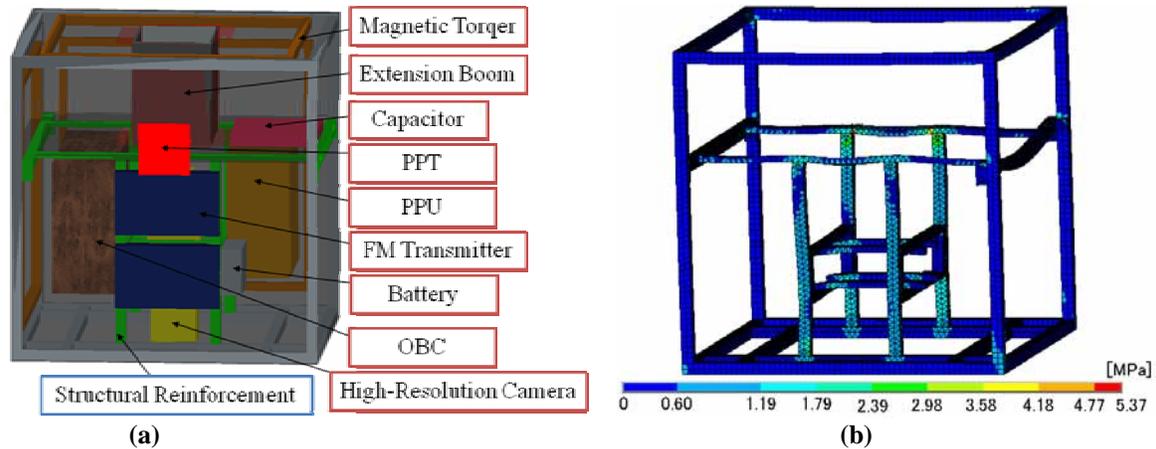


Figure 15. Engineering flight model of PROITERES ,(b)structure under ANSYS analysis and static analysis.

#### D. Onboard computer system

Figure 16 shows the system diagram of PROITERES satellite. The command and data handling system of the satellite is characterized by these features that

- 1) it has 2 main computers;
- 2) the computers run under Linux operating system, and
- 3) the computers make TCP/IP based local area network.

They are all for durability as well as higher performance. Two computers watch each other work properly and each one can reboot the other when it fails. Some of the most important tasks such as attitude control are executed by both computers for redundancy while other tasks are allocated among them for load balancing.

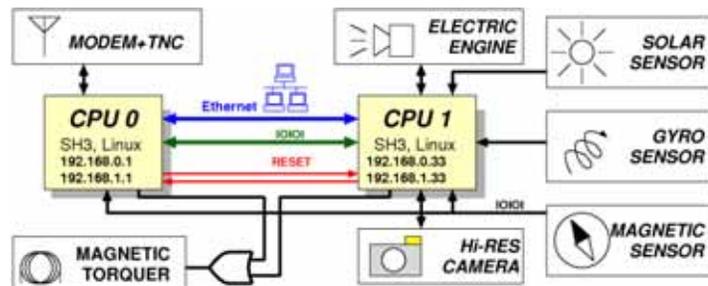


Figure 16. C&DH system of PROITERES satellite.

Figure 17 shows a commercially-aveirable computer board selected for PROITERES satellite. The board computer of SH7709 and CAT709, as shown in Figure 18, was irradiated to Gamma rays 64 krad, at Radiation Research Center, Osaka Prefecture University, and before and after, and during irradiation, running of computer program was checked and completely accepted.

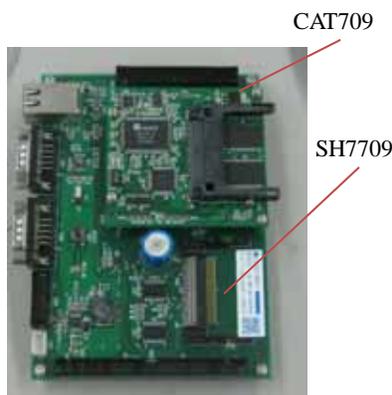


Figure 17. C&DH system of PROITERES satellite.



Figure 18. Gama rays exposure tests for OBC.

## E. Communication system and ground station

Figure 19 shows the satellite link overview. The satellite communication system is equipped for the following purposes:

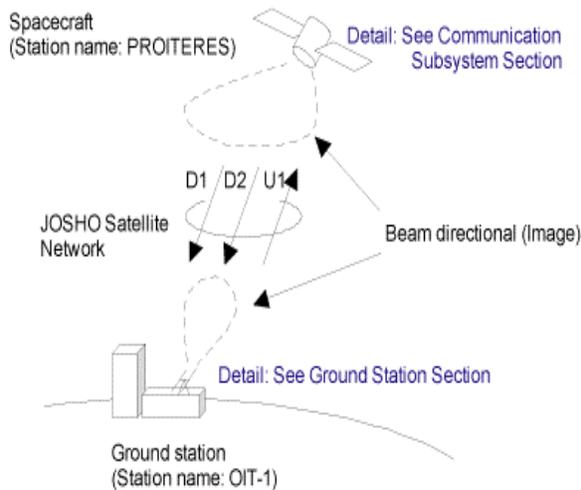
- 1) Mission data transmission
- 2) Control and maintenance of the satellite
- 3) Support to tracking of the satellite

The PROITERES Satellite network has three beams listed as follows:

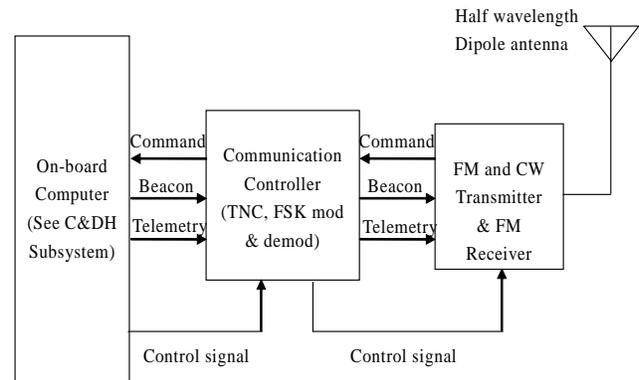
- 1) Down-link: D1 beam (Telemetry: FM/BFSK)
- 2) Down-link: D2 beam (Beacon: CW/Morse)
- 3) Up-link: U1 beam (Command: FM/BFSK)

All communications are scheduled to be executed in the frequency of 430MHz.

Figure 20 shows the subsystem Block diagram. The components are follows:



**Figure 19. Satellite link overview.**



**Figure 20. Block diagram of communication subsystem.**

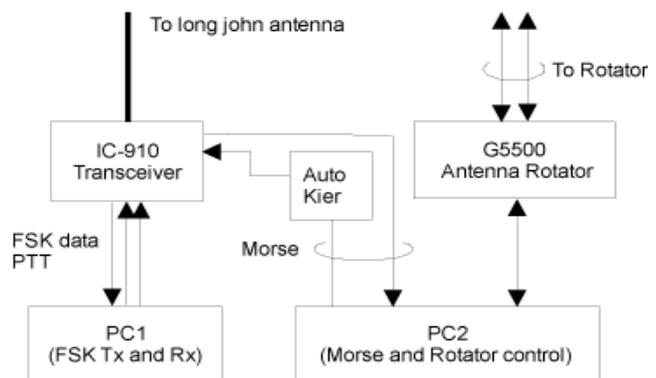
- 1) Transmitter and receiver (Nishi RF Lab. Custom made module) This module transmits AX.25 packet (telemetry data) to the ground station by FM method with speed of 1200bps via the dipole antenna. The module also transmits Morse codes (beacon signal) to the ground station. As for the receiver function, this module receives FM signal (command) and send AX.25 packet to TNC in communication controller.
- 2) Communication controller (UNISEC Custom made module)

The communication controller mediates onboard computer and the Nishi RF Lab. module. Functions of this unit are follows:

- i) Capsulation of AX.25 packet (Terminal Node Controller),
- ii) Modulation and demodulation of binary FSK (BFSK) data,
- iii) Configure the phase lock loop and frequency, PTT of Nishi RF Lab. module

- 3) Antennas

In PROITERES satellite, the same frequency, 430MHz band is used for the transmission and the reception.



**Figure 21. Ground station block diagram.**

Thus one antenna is installed in the satellite. As for installation antenna type, we are concerning some antennas of half wavelength dipole antenna and inverted L antenna.

Figure 21 shows the ground station block diagram prepared at Omiya campus, Osaka Institute of Technology, Osaka. This system is one of popular and commercially-aveirable systems in ground.

### F. Electric power system

Electric power is generated by silicon solar cells on five surfaces of the satellite except for the bottom surface. The minimum electric power of 10 W will be generated by each surface. Two bus voltages of 5 and 12 V are provided, and that of 12 V is used for electrothermal PPT operation. Lithium ion batteries with some charging circuit are onboard PROITERES satellite.

### G. Attitude control system

Attitude control systems with magnetic torquers, 3-axis magnetic and gyro sensors, and sun sensors are being developed.<sup>3</sup>Six magnetic coils are used for generation of magnetic fields. The attitude of PROITERES satellite can be controlled by magnetic torque, which is created by interaction between the geomagnetic field and the magnetic field generated with the coils in the satellite. The sun sensor detects the direction of the Sun with arrangement of a linear photo sensor and a slit.

### H. Thermal control

Figure 22 shows time variations of satellite temperature analyzed by ANSYS. We checked safe temperatures of all devices inside the satellite. Thermal vacuum tests are under way.

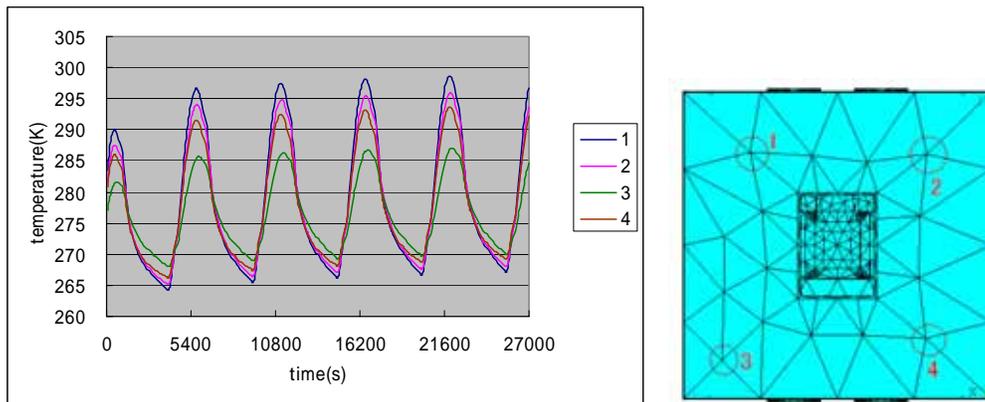


Figure 22. Time variations of satellite temperature.

## V. Conclusion

The Project of Osaka Institute of Technology Electric-Rocket-Engine onboard Small Space Ship (PROITERES) was started at Osaka Institute of Technology in 2007. In PROITERES, a small satellite with electrothermal pulsed plasma thrusters (PPTs) will be launched in 2010. The main mission is to achieve powered flight of small satellite by an electric thruster and to observe Kansai district in Japan with a high-resolution camera. We developed Bread Board Model (BBM) and Engineering Model (EM) of the satellite, including electrothermal PPT system, high-resolution camera system, onboard computer system, communication system and ground station, electric power system and attitude control system etc, in 2007-2008. PROITERES is successfully under way.

## References

- <sup>1</sup> Yamada,M., “Progress of Project of Osaka Institute of Technology Electric-Rocket-Engine onboard Small Space Ship (PROITERES)” *Symposium on Space Transportation*,2009 in Japanese.
- <sup>2</sup> Takagi, H., Ishii, Y., Yamamoto, T., and Tahara, H., “Electrothermal Pulsed Plasma Thrusters for Project of Osaka Institute of Technology Electric-Rocket-Engine onboard Small Space Ship (PROITERES)” *26th International Symposium on Space Technology and Science, Hamamatsu*, Paper No. ISTS2008-b-54p, June2008.
- <sup>3</sup> Ikeda, T., Yamada,M., Tahara,H., Team of Students and Faculty Members of Osaka Institute of Technology., “Features of Project of OIT Electric-Rocket-Engine onboard Small Space Ship” *45<sup>th</sup> Chubu/Kansai Branches, Japan Society for Aeronautical and Space Sciences*, 2008 in Japanese.