Research and Development of the Osaka Institute of Technology 2nd PROITERES Nano-Satellite with High-Power Electrothermal Pulsed Plasma Thrusters for Powered Flight

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Abstract: The launch of the 2nd PROITERES nano-satellite was determined in 2018. It will be boardded as a piggyback payload of GOSAT-2 and KhalifaSat in H-IIA Rocket by JAXA. The main mission of the 2nd PROITERES nano-satellite is to achieve powered flight 50-100 km in altitude with Multi-Discharge-Room electrothermal pulsed plasma thrusters (MDR-PPT). If altitude control is successful, possibility of small-satellites will be widened.

Nomenclature

V_{Bave} = Average voltage of battery
V_{Bmax} = Maximum voltage of battery
V_{Bmar} = Margin of voltage of battery
V_{BAT} = voltage of one battery
V_{BA} = voltage of battery assembly

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V_{Smp} = Rating voltage of SAP (Solar Array Panel)
V_{SAmp} = voltage of SAP assembly
I_B = Current of battery
I_{Smp} = Rating current of SAP
I_{SAmp} = Rating current of SAP assembly
P_{Smax} = Maximum power consumption of SAP
P_{cc} = Power consumption of charge mode
P_{cw} = Power consumption of wait mode
P_{cm} = Power consumption of mission mode
P_{SA} = Power of SAP assembly
P_{mc} = Power consumption of charge step in mission mode
W_{cc} = Electric energy consumption of charge mode
W_{cw} = Electric energy consumption of wait mode
W_{co} = Electric energy consumption of operation (charge mode + wait mode)
W_{BA} = Electric energy of battery Assembly
W_{BAT} = Electric energy of battery
W_{SA} = Electric energy of SAP (Solar Array Panel) assembly
W_{SAP} = Electric energy of SAP only
W_{SAL} = W_{SA} considering the loss
Q_B = Capacitance of battery
Q_{BA} = Capacitance of battery assembly
N_{Bpar} = Parallel number of batteries
N_{Spar} = Parallel number of SAPs

I. Introduction

Until now, most all mainstream satellites have been large-sized. However small-sized satellites are becoming more popular because their development period is shorter and cost is cheaper. Previous small-/nano-satellites didn't have a thruster for altitude change. If altitude control is successful, possibility of small-satellites will be widened.

II. PROITERES

The Project of Osaka Institute of Technology Electric Rocket Engine onboard Small Space Ship (PROITERES) was started in 2007. In this project, the research and development of the nano-satellite named "1st PROITERES nano-satellite" with electrothermal pulsed plasma thrusters (PPTs) were carried out. The main mission is to achieve powered flight (change orbital altitude) of a nano-satellite by PPTs and to observe Kansai district in Japan with a high-resolution camera. The 1st PROITERES satellite was launched on a sun-synchronous orbit of 660 km in earth altitude by PSLV C-21 launcher at Satish Dhawan Space Center (SDSC), Indian Space Research Organization (ISRO) on September 9th, 2012.

Now, the "2nd PROITERES nano-satellite" with new PPT system, i.e., electrothermal PPT system which can generate large-total-impulse are researched and developed.

III. The 2nd PROITERES nano-satellite

The launch of the 2nd PROITERES satellite was determined in 2018. It will board as a piggyback payload of GOSAT-2 (in Japan) and KhalifaSat (in UAE) in H-IIA Rocket by JAXA.

The main mission of 2nd PROITERES satellite is to achieve a longer powered flight than that of the 1st PROITERES satellite by the PPT. The New PPT system, Multi-Discharge-Room PPT (MDR-PPT) for long-range powered flight and long-time operation, was innovated. Then Bread Board Model (BBM) of the 2nd PROITERES satellite was developed.

This project is divided into a propulsion system, a structural system, a C&DH (Command and Data Handling) system, a communication system, an attitude control system, a power system and an outfitting system developing.

A. Specifications of the 2nd PROITERES

Specification of the 2nd PROITERES satellite is as follows. Image of the 2nd PROITERES nano-satellite is shown in Figure 1, the specification of the 2nd PROITERES nano-satellite is shown in Table 1.

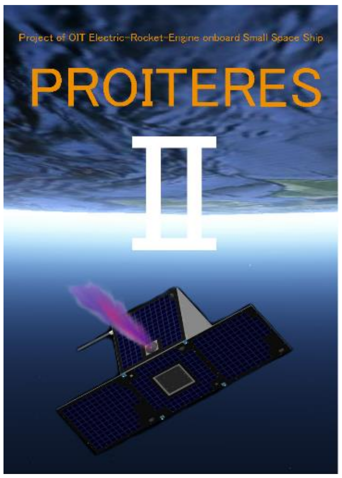


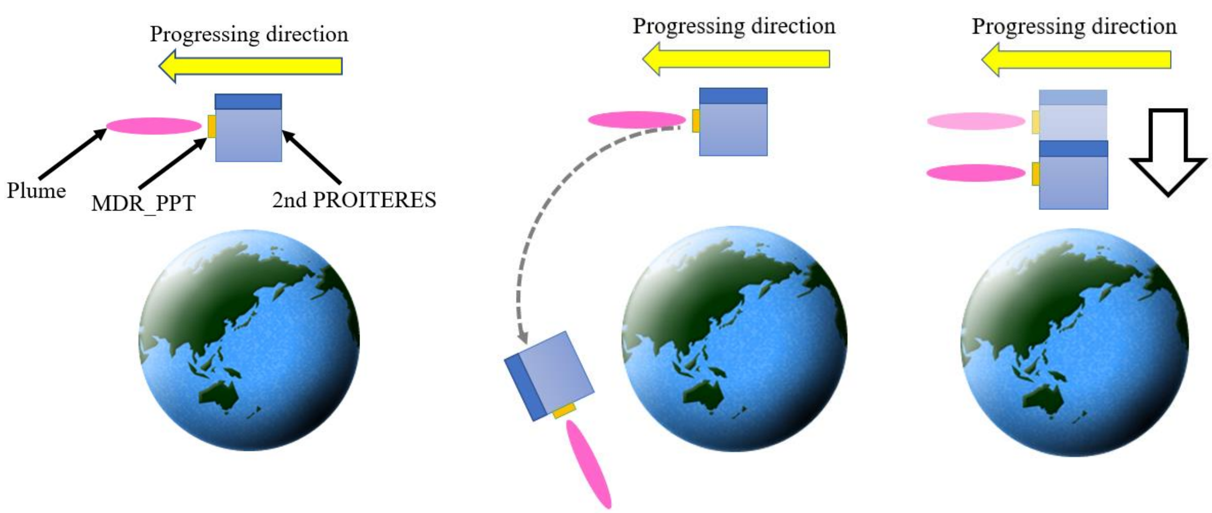
Figure 1. Image of 2nd PROITERES satellite.

Table 1. Specification of 2nd PROITERES satellite.

Mass, kg	45
Outside dimension, mm	470 x 470 x 450
Electric power, W	60
Altitude, km	613
Launch time	2018 Summer
Life time, year	1 - 2
Attitude control	3 axis controls
Main mission	Powered flight by MDR-PPT

B. Operation

The main mission of the 2nd PROITERES nano-satellite is powered flight with the MDR_PPT. The 2nd PROITERES nano-satellite performs orbit descent by the MDR_PPT. The image of orbit descent is shown in the Figure 2. also the operation of the satellite is as follows. A conceptual diagram is shown in the Figure 3.



a) Mission start b) Powered flight c) Mission complete

Figure 2. Image of the main mission.

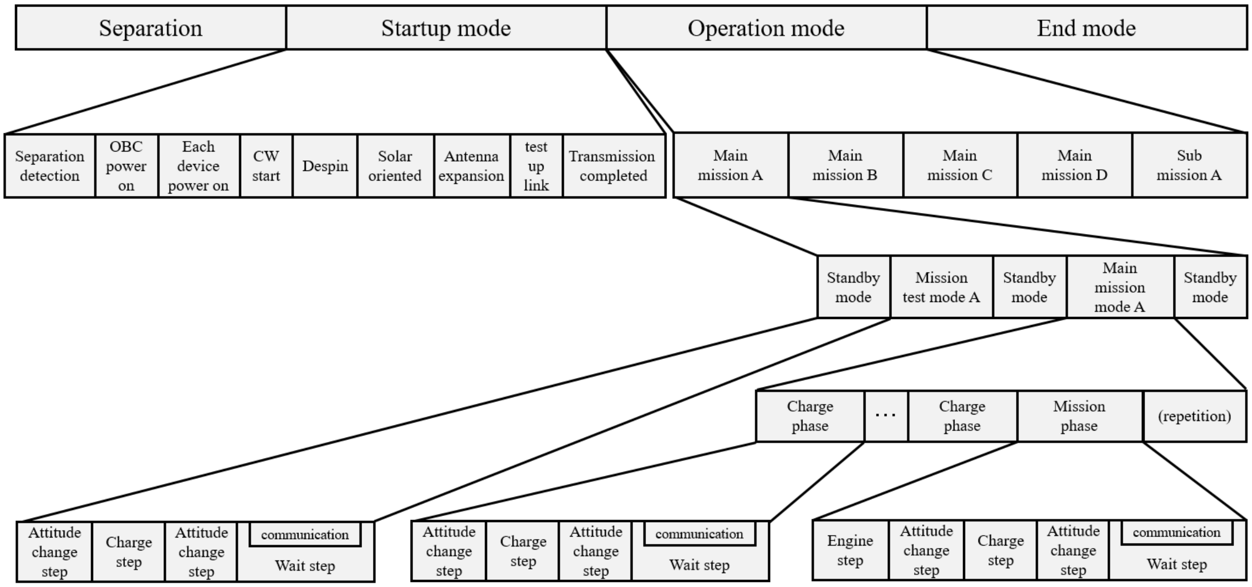


Figure 3. Conceptual diagram of satellite operation.

After separation from the rocket, the 2nd PROTERES nano-satellite operates in the order of "Start mode", "Operation mode" and "End mode".

Startup mode

In the Startup mode after separation for rocket, power on each device, attitude control, antenna expansion and test communication in order to shift to the regular operation. The order of the Startup mode is as follows.

1) Detection of separation (with a separation switch)
2) Power on OBC
3) Power on each device
4) CW radiation start
5) Despin by Reaction Wheel
6) Solar oriented
7) Antenna expansion
8) Test up-link
9) Completion of communication
10) Transition to the Operation mode

Operation mode

Operation mode performs communication, main mission and submission. The main mission is from A to D, and an injection test corresponding to each discharge room is performed. The main mission repeats Charge step (shine time; Solar oriented) and standby step (shadow time; earth pointing), and performs jetting as soon as it is fully charged. The operation mode is as follows. In order to operate safely, the PPT is operated 10 shots before performing, then, each discharge room is operated for 80,000 shots (total 560,000 shots).

1) Start of "Main mission A"
2) Command reception
3) Test mission mode (operated 10 shots)
4) Standby mode (charge step and standby step)
   4-1) Charge step
   4-2) Standby step

4-3) Repeat charge step and standby step
5) Command reception
6) Main mission mode
   6-1) Charge step
   6-2) Standby step
   6-3) Engine step
   6-4) Repeat charge step and standby step
7) S_PPT1 all injection completed
8) Standby mode
9) (Perform until "Main mission D")

IV. Onboard equipments

The following on-board equipment is used for the 2nd PROITERES nano-satellite. The table2 is a list of mounted devices, and it shows the number and whether it is self-made.

Table 2. Equipment in 2nd PROITERES satellite.

Onboard equipment	Acronym	Number of units	Self-made
PPT system	MDR_S	1	Y
Expansion paddle	EPD	0	N
Reaction wheel	RW	4	N
Magnetic torquer	MTQ	3	Y
Sun sensor	SSS	5	Y
Angular rate sensor	GSS	3	N
Earth sensor	ESS	1	N
Magnetic Sensor	MSS	1	N
Transmitter and receiver	TAO	1	N
Antenna	ANT	2	Y
On board computer	OBC	2	N
Battery and power unit	BAT/PCU	1	Y

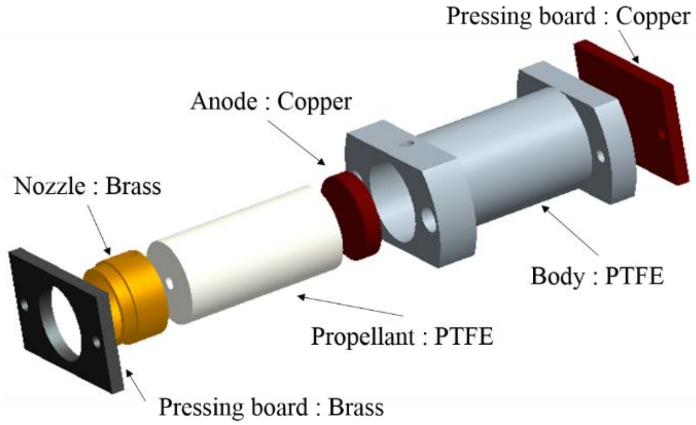
(Y: Yes, N: No)

A. Pulsed Plasma Thrusters (PPT)

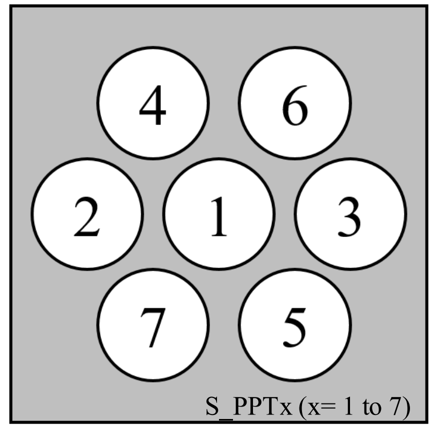
For the 2nd PROITERES nano-satellite, a long-time operation PPT system is required to change the altitude/orbit. Therefore, a new PPT system with the Multi-Discharge-Room type electrothermal PPT (MDR-PPT) was developed at OIT. The MDR-PPT has plural discharge rooms in one single thruster. The ignitors are mounted in each discharge room and can be selected separately to change the discharge room. 1 discharge room is called S_PPT. The MDR-PPT for mounting the 2nd PROITERES nano-satellite has 7 S_PPT's.

The MDR-PPT uses an anode panel and a cathode panel as a structure and an electrode. In the present design, it becomes the 2 points grounding of the capacitor and the cathode. Therefore, the team changed the anode panel / cathode panel to insulator and wire directly to the anode / cathode. Furthermore, to secure the strength, the team attached the aluminum frame. Furthermore, an aluminum frame was attached to ensure strength. Figure 4 shows the structure and placement of S_PPT. Figure 5 shows the modified MDR-PPT.

The PPT system for mounting the 2nd PROITERES nano-satellite consists of the MDR-PPT head and a capacitor (13 mica paper capacitors connected in parallel) and a PPU. Each device is housed in a housing. The capacitor and the MDR-PPT head were placed as close as possible to reduce the energy loss due to the resistance of the circuit cable. Also, the placement of each device was decided considering the position of the center of gravity at the time of mounting on the satellite. The designed PPT system is shown in Figure 6, and the size of each device is shown in Table 3.

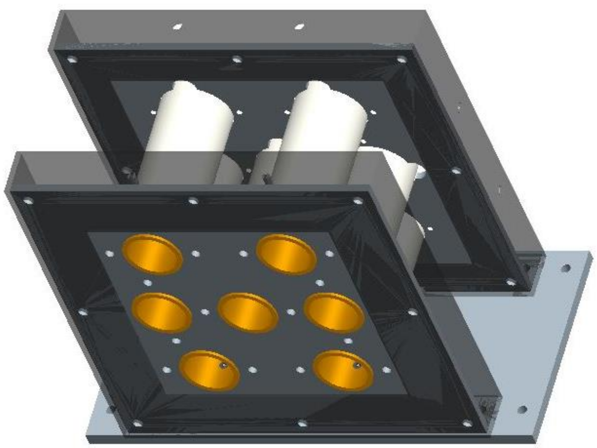


a) Structure of S_PPT.

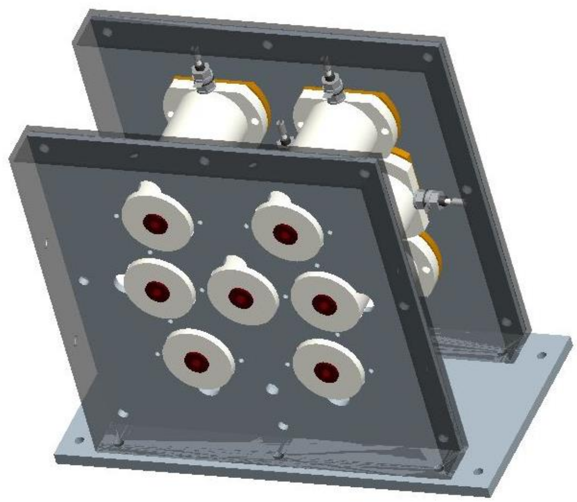


b) placement of S_PPT.

Figure 4. Structure and placement of single head PPT (S_PPT) for MDR-PPT.



a) Front side.



b) Back side.

Figure 5. 3D model of MDR-PPT head.

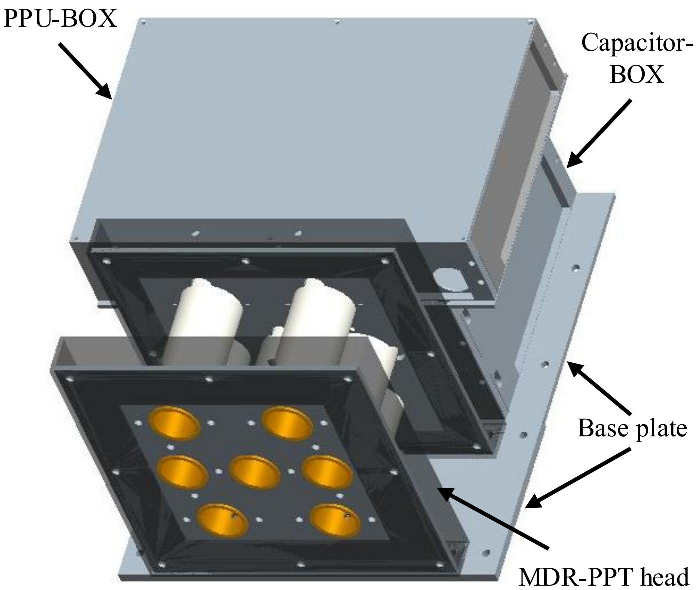


Figure 6. PPT system.

Table 3. Size of PPT system.

PPT system, mm	197 x 221 x 162
MDR-PPT head, mm	159 x 89 x 162
PPU-BOX, mm	197 x 132 x 47
Capacitor-BOX, mm	150 x 122 x 85

If this powered flight, which is the main mission of the 2nd PROITERES nano-satellite, can be achieved with this PPT system, it can be expected to be diverted to other small/nano satellites. Moreover, by changing the number of discharge chambers of the MDR-PPT head and the number of mica paper capacitors, the range of the mission can be expanded.

B. Battery/ Power supply unit

The sizing of the battery and the solar cell was obtained from the operational of the satellite and the mission. The design conditions are shown below.

・Battery : The eneloop pro : V_{Bave}=1.2V, I_B=2500mAh
・Solar cell : GaAs type : V_{Smp} = 2.4V, I_{Smp} = 0.5A, P_{Smax} = 1.2 W
・The operation period is 1 year maximum.
・Perform 560,000 shots (80,000 shots x7 discharge room) of PPT within the operational period.
・PPT of 1 shot operation is 1.5 seconds.
・Loss due to power conversion efficiency is estimated to be 10%.
・It is assumed that power generation by the SAP (Solar Array Panel) in the global orientation is 0, and it generates electricity only with the solar oriented.
・The mission shall be carried out once the battery is fully charged.
・The shadow is always a standby step, and the shine is a charging step. As soon as the battery is full charged, the engine step is started when the shine rushes in.
・The power consumption was calculated from the on-board equipment of each step.
・The power consumption of each step is as follows.

Charge step Pcc=10.8W
Standby step Pcw=11.7W
Engine step Pcm=43.6W

Operation form of the mission

In the shine 45 minutes, it consumes 11.7 W of power because it is in charge step. In the shadow 45 minutes, it consumes 11.7 W of power because it is in standby mode. In the charge step, the electric energy W_{cc} is as follows.

$$W_{cc}=P_{cc}\times(45/60)=10.8\times(45/60)=8.1\text{ Wh}$$

In the standby mode, the electric energy W_{cw} is as follows.

$$W_{cw}=P_{cw}\times(45/60)=11.7\times(45/60)=8.8\text{ Wh}$$

The total lap W_{co} is as follows.

$$W_{co}=W_{cc}+W_{cw}=8.1+8.8=16.9\text{ Wh}$$

From the above calculations, it is absolutely necessary to charge more than 16.9 Wh in the charge step for 45 minutes.In other words, we must design the size of SAP that can generate 16.9 Wh or more at least for 45 minutes.

Design of voltage of battery and solar cell

The voltage of the battery is designed according to 28 V of PPT which has the highest operating voltage among the mounted equipment.

The depth of discharge was set at 25% to suppress cycle deterioration. Therefore, the performance of one battery cell was set to the maximum voltage V_{max} = 1.45 V, average voltage V_{ave} = 1.2 V, capacity Q_B = 625 mAh.

The Eneloop pro average voltage is 1.2 V, it becomes 28.8 V in 24 series. The performance of the battery in this case is voltage V_{BA} = 28.8 V, capacity Q_{BA} = 625 mAh, power amount W_{BA} = 18 Wh. And voltage V_{BA} = 28.8 V, capacity Q_{BA} = 1250 mAh, power amount W_{BA} = 36 Wh in case of 2 parallel.

The number of series connected solar cells is calculated in consideration of the full charge voltage V_{Bmax} (1.45 V) of the battery cell and the deterioration consideration V_{Bmar} (+ 4 V) as follows.

$$V_{BAT}=V_{Bmax}\times N_{Bpar}+V_{Bmar}=1.45\times24+4=38.8\text{V}$$

The number of sheets required to output this voltage is as follows.

$$N_{Spar}=V_{BAT}/V_{Smp}=38.8/2.4=16.2$$

In other words, it becomes 17 sheets. And the output voltage V_{SA} becomes V_{SA} = 40.8 V.
The performance of the 17 series solar cell is V_{SAmp} = 40.8 V, I_{SAmp} = 0.5 A, P_{SAmax} = 20.4 W.
In this case, at 45 minutes of sunshine, the power amount W_{SA} is as follows.

$$W_{SA}=P_{SAmax}\times(45/60)=20.4\text{W}\times(45\text{m}/60\text{m})=15.3\text{Wh}$$

However, since it is less than 16.9 Wh, which is the power consumption of one lap, 17 series and one parallel is not enough. In the case of 17 series 2 parallel, PSA = 40.8 W, WSA = 30.6 Wh can be generated. Therefore, performance of 17 serial 2 parallel or higher is required.

Consideration of power conversion loss

10% when storing electricity from SAP to battery, assume that a loss of 10% occurs when being supplied from the battery to the onboard equipment. In this case, since the electric power used in the onboard equipment is 81% of the generated electric power of SAP, the electric power amount W_{SAL} which can actually be used is as follows.

$$W_{SAL}=W_{SA}\times0.81=30.6\text{Wh}\times0.81=24.8\text{Wh}$$

Therefore, the generated power amount W_{SAL} when the satellite makes 1 lap is 24.8 Wh, the power consumption W_{CO} is 16.9 Wh, and the power amount of about 7.9 Wh is left in the battery per 1 lap.

Electricity balance of the mission phase

Since it is in the standby mode in the shadow, 8.8 Wh is consumed in 45 minutes. Mission mode is consumed 43.6 W. The size of the battery can store 18 Wh in 24 series and 1 parallel, 36 Wh in 2 parallels, and 54 Wh in 3 parallels.

The power balance is the size of the solar cell by 17 series and 2 parallel meters totaling 34, the size of the battery is analyzed separately for each of the following cases, we selected the size of the battery suitable for the operation of the 2nd PROITERES nano-satellite.

Pattern 1 : 24 series and 1 parallel
Pattern 2 : 24 series and 2 parallels
Pattern 3 : 24 series and 3 parallels

The electric power balance when the satellite makes 1 lap of the earth must satisfy the following relation.

$$W_{SAP} + W_{BAT} \geq W_{cm}$$

The electric power balance was made for the case where the size of the battery was 1 parallel, 2 parallels, and 3 parallels, and it was decided in consideration of merit and demerit.

In case of 1 parallel
Merit : The number of cells is the smallest with 24 cells.
Demerit : Since it is necessary to change attitude multiple times in the mission phase, the difficulty level of operation is the highest.

In case of 2 parallels
Merit : Operation difficulty is easy compared to 1 parallel.
Demerit : It is impossible to devote all of the shadow 45 minutes to the mission.

In case of 3 parallels
Merit : Since it is possible to devote everything to the mission for 45 minutes in the shadow, the difficulty of operation is the easiest.
Demerit : Despite the increase in size, the operation period is almost the same as 2 parallels.

From these results, in one parallel case, the number of times of attitude change increases and the difficulty level of operation is high. In the case of 3 parallels, it is compared with 2 parallels, and it does not change much during the operation period. From the above, the team considered that 2 parallels are the most suitable value for the 2nd PROITERES nano-satellite.

Power balance of 2 parallel (36 Wh)

The power balance of the mission mode at two parallel calculations was calculated. A conceptual diagram of satellite operation is shown in Figure 7.

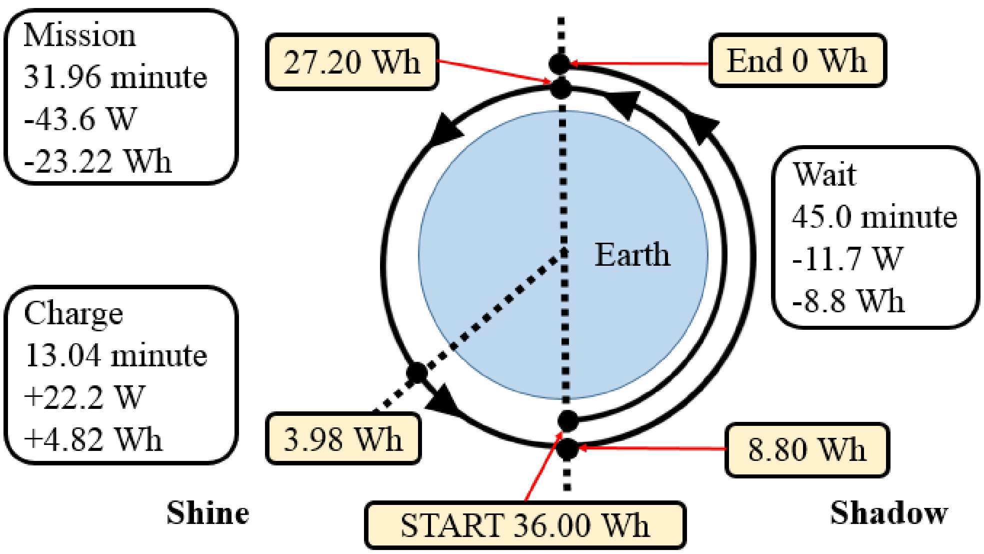


Figure 7. The mission phase of power balance.

The power balance equations are as follows.

$$W_{BA}+P_{mc}\times\{(45-T_m)/60\}=(Pcc+Pcw+Pcm)\times(T_m/60)$$
$$T_m = 31.96 \text{ minutes}$$

Consume 8.8 Wh in 45 minutes of shadow. The remaining battery power at the shine entry is 27.2 Wh. When the mission mode is performed for 31.96 minutes, the remaining battery power becomes 3.98 Wh. After that, 4.82 Wh is stored in the charge step of 13.04 minutes, so enter the shadow leaving 8.8 Wh. 16.65 Wh charged in 45 minutes of shine. 8.8 Wh consumed in the shadow. In this case, 7.85 Wh is stored in the battery every lap. This is repeated until the battery reaches 36 Wh, which is the full charge. It is fully charged at the shine of 33.65 minutes on the 4th lap of the charge phase. Table 4 shows the transition of the power balance of the charge phase. Figure 8 shows the transition of the power balance for 1 operational cycle.

Table 4. Power balance of charge phase.

Lap	**Sunshine or Shadow**	**Time(total), minute**	**Capacity, Wh**	
			Total	**Increase and decrease**
1st lap	Sunshine (Charging)	0	0	+16.65
		48(48)	16.65	
	Shadow (Discharge)			-8.80
		96(96)	7.85	
2nd lap	Sunshine (Charging)	0(96)	7.85	+16.65
		48(144)	24.5	
	Shadow (Discharge)			-8.80
		96(192)	15.7	
3rd lap	Sunshine (Charging)	0(192)	15.7	+16.65
		48(240)	32.35	
	Shadow (Discharge)			-8.80
		96(288)	23.55	
4th lap	Sunshine (Charging)	0(288)	23.55	+16.65
		33.65(321.65)	36.00	
	Shadow (Discharge)			-8.80
		----	36.00	

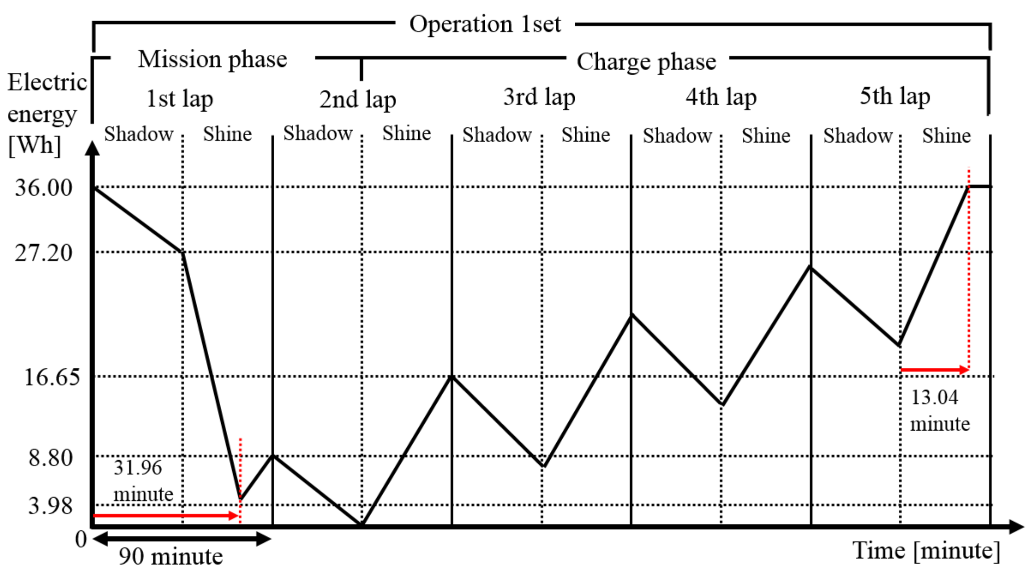


Figure 8. Power balance time series of 2 parallel battery.

Operation of the satellite was 1 lap of the mission phase, 4 laps of the charge phase, a total of 5 laps, and it became 1 cycle. In this case, the time taken for 1 cycle is 90 minutes × 5 laps = 450 minutes. Within that 31.96 minutes (about 1916 seconds) the mission can be executed. Therefore, to end the engine of 700,000 shots (1, 050,000 seconds), it is necessary to operate 549 sets. The operation period under this condition can be completed in about 172 days (247,050 minutes).

PCU：Power Control Unit

The PCU is connected as shown in the power wiring diagram shown in Figure 9 below. Since the voltages from SAP and BAT are supplied in accordance with the maximum voltage of 28 V of PPT, 12 V, 5 V are stepped down in PCU.

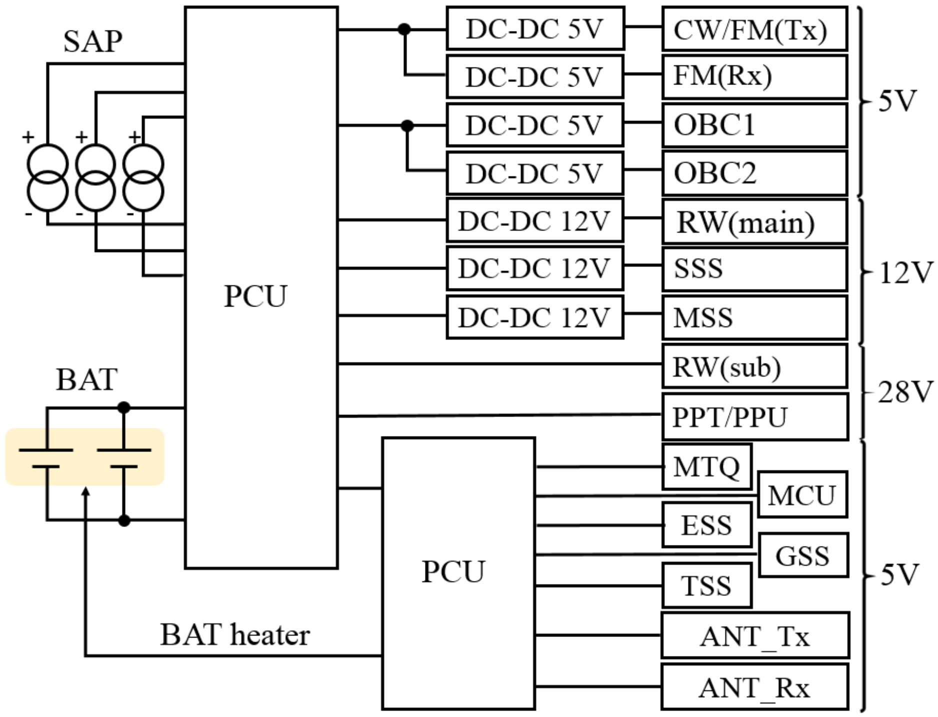


Figure 9. Power connection diagram for the 2nd PROITERES nano-satellite.

C. OBC/MCU

OBC has two RaspberryPi model B+. In order to monitor two OBCs, one Mbed is nounted as an MCU. Also, when passing through a place with a high radiation concentration called “SAA: South Atlantic Anomaly”, turn off the power of the OBC and restart it with a timer. A diagram of RaspberryPi is shown in Figure 10.

Figure 10. Diagram of RaspberryPi.

D. Communication equipment

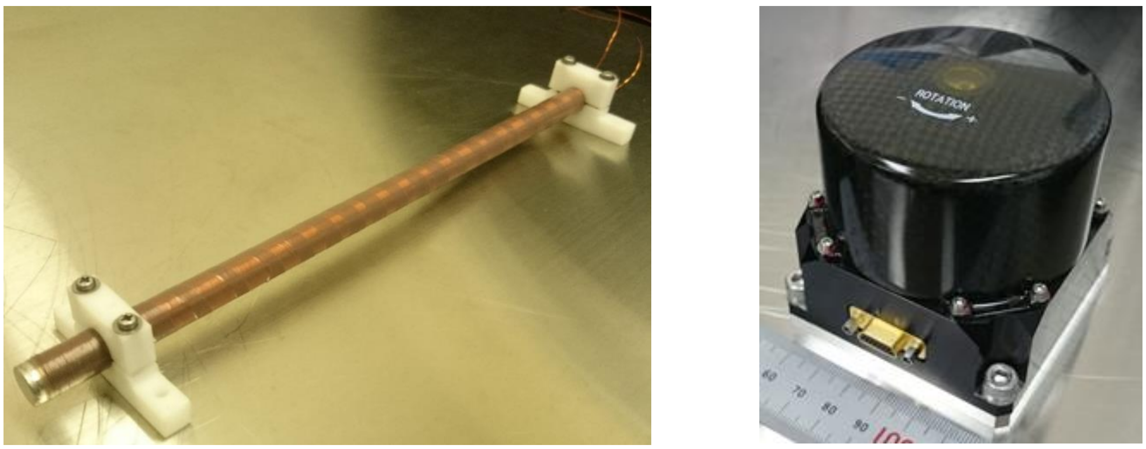
As for communication equipment, it is the same as the 1st PROITERES nano-satellite, and a transceiver manufactured by West Radio Co. is installed. However, in response to a recommendation (Recommendation) that the 430 MHz band can’t be used for downlink from IARU (International Amateur Radio Union), exchange frequency of transmission and reception is used (The downlink uses the 145 MHz band). A copper pipe with an outer size of 3 mm and a wall thickness of 0.5 mm is used for a satellite antenna. Table 5 shows the frequency band used by the transceiver.

Table.5 Specification of frequency.

	Frequency band	Communication rate	Modulation method
CW (Down-link)	145.80 – 146.00 MHz	50 WPM	-----
FM (Down-link)	145.80 – 146.00 MHz	1200 bps	AFSK/FM
FM (Up-link)	435.00 – 438.00 MHz	1200 bps	AFSK/FM

E. Actuator

3axis magnetic torquer and reaction wheel are used for the actuator. The magnetic torquer uses what we made ourselves at our university. The reaction wheels are used for attitude control, and the magnetic torquer is used for unloading. The reaction wheels and the magnetic torquers are shown in the figure 11.



a) Magnetic torquer b) Reaction wheel

Figure 11 Actuator to be mounted in 2nd PROITERES nano-satellite.

F. Sensor

The sensor uses a sun sensor, magnetic sensor, gyro sensor and earth sensor. The sun sensor uses self-made. The sun sensor is shown in the Figure 12.

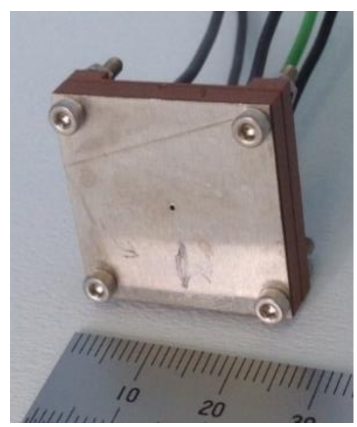


Figure 12. Sun sensor.

V. Structure of the 2nd PROITERES nano-satellite

The structure of 2nd PROITERES nano-satellite is configured as shown in Figure 13. The main structure and outer skin are composed of a honeycomb aluminum plate, aluminum frame of A5052 is set at the four corners.

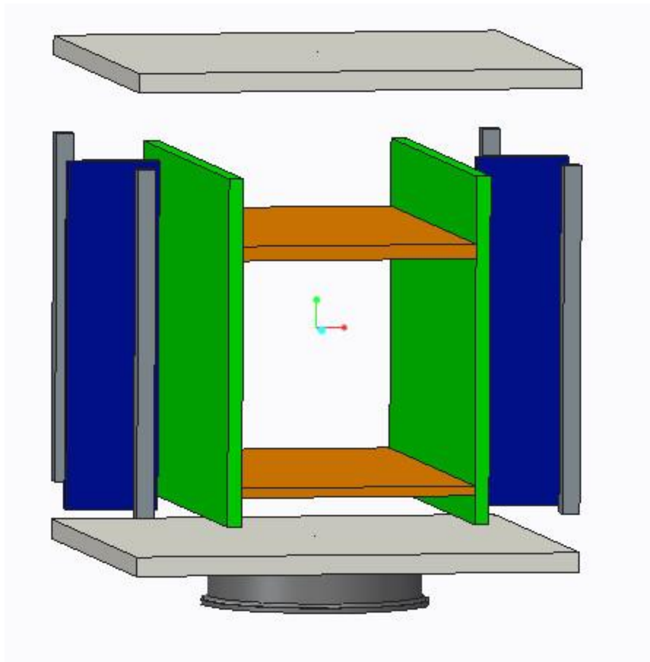
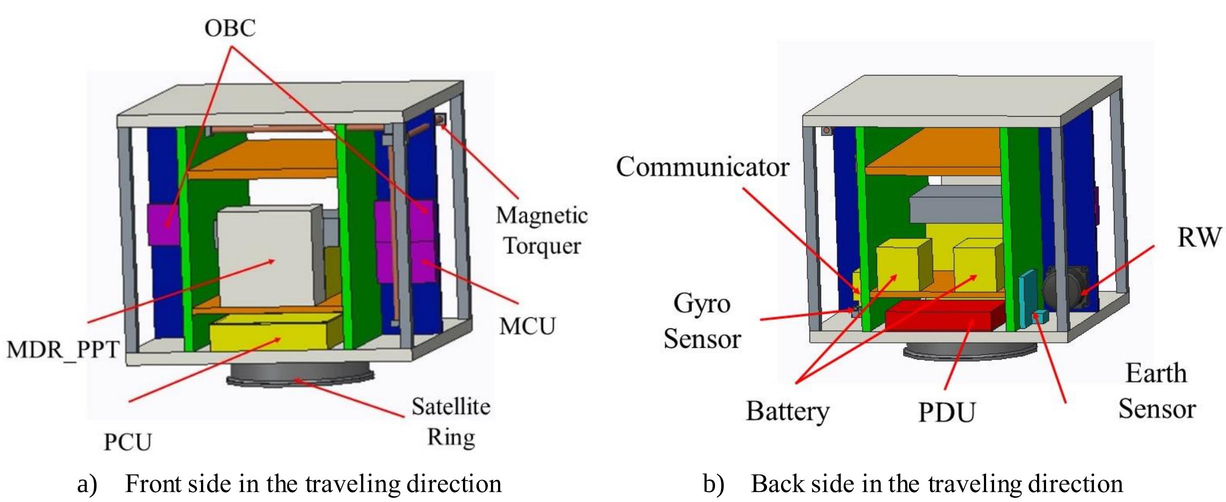


Figure 13. Configuration diagram of 2nd PROITERES nano-satellite.

As for the arrangement of MDR_PPT, mount the base plate so that S_PPT1 is placed at the center of gravity. It is necessary to place equipment in consideration of the influence of heat generation from equipment, wiring, equipment interference and space environment. After placing equipment, the 3D model performs structural analysis and thermal analysis using analysis software. The analysis content is gravitational acceleration load analysis, sine wave vibration analysis and random vibration analysis. For analysis, Creo simulate and Thermal Desktop are used. The equipment arrangement diagram of 2nd PROITERES nano-satellite is shown in Figure 14.



a) Front side in the traveling direction b) Back side in the traveling direction
Figure 14. The equipment arrangement diagram of 2nd PROITERES nano-satellite.

VI. Conclusions

The launch of the 2nd PROITERES nano-satellite was determined in 2018.

The MDR_PPT in 2nd PROITERES nano-satellite was developed.

The sizing of the battery and the solar cell was obtained from the operational of the satellite and the mission. the team considered that 2 parallels are the most suitable value for the 2nd PROITERES nano-satellite.

Operation of the satellite was 1 lap of the mission phase, 4 laps of the charge phase, a total of 5 laps, and it became 1 cycle. the time taken for 1 cycle is 450 minutes. Within that 31.96 minutes (about 1916 seconds) the mission can be executed. Therefore, to end the engine of 700,000 shots (1, 050,000 seconds), it is necessary to operate 549 sets. The operation period under this condition can be completed in about 172 days (247,050 minutes).

The main structure and outer skin of 2nd PROITERES nano-satellite are composed of a honeycomb aluminum plate, aluminum frame of A5052 is set at the four corners.

References

[1]Kamimura, T. and Tahara, H., (2014) 'R&D, Launch and Initial Operation of the Osaka Institute of Technology 1st PROITERES Nano-Satellite with Electrothermal Pulsed Plasma Thrusters and Development of the 2nd and 3rd Satellites', AIAA Propulsion and Energy Forum and Exposition 2014, Cleveland, USA.

[2]Fujita, R., Muraoka, R., Hunnjun, C., Kisaki, S., Tanaka, T., Tahara, H., and Wakizono, T., (2014) 'Development of Electrothermal Pulsed Plasma Thruster Systems onboard Osaka Institute of Technology PROITERES Nano-Satellites', AIAA Propulsion and Energy Forum and Exposition 2014, AIAA-2014-3610, Cleveland, USA.

[3]Kamimura, T., Nishimura, Y., Ikeda, T. and Tahara, H., (2015) 'R&D and Final Operation of Osaka Institute of Technology 1st PROITERES Nano-Satellite with Electrothermal Pulsed Plasma Thrusters and Development of 2nd and 3rd Satellites' 30th International Symposium on Space Technology and Science (30th ISTS), 34th International Electric Propulsion Conference (34th IEPC), 6th Nano-Satellite Symposium (6th NSAT), IEPC-2015-209/ISTS-2015-b-209, Kobe, Japan.

[4]Kojima, Y., Kamimura, T., Nishimura, Y., Ikeda, T., Fujita, R., Tahara, H. and OIT PROITERES Team, (2015) 'R&D and Final Operation of Osaka Institute of Technology 1st PROITERES Nano-Satellite with Electric Rocket Engines and Development of 2nd and 3rd Satellites', 30th International Symposium on Space Technology and Science, 34th International Electric Propulsion Conference, 6th Nano-Satellite Symposium, ISTS-2015-f-13, Kobe, Japan.

[5]Kanaoka, K., Fujita, R., Ryuho, K., Ono, K., Morikawa, N., Enomoto, K., Tahara, H., Takada, K. and Takashi W., (2016) 'Development of 30 J-class Electrothermal Pulsed Plasma Thruster Systems for Powered Flight onboard the Osaka Institute of Technology 2nd PROITERES Nano-Satellite' APISAT-2016.

[6]Fujita, H., Yamauchi, T., Kamimura, T., Tahara H. and Takada K., (2016) 'Development of Osaka Institute of Technology Nano-Satellite PROITERES-2 with High-Power Electrothermal Pulsed Plasma Thrusters' 8th Asian Joint Conference on Propulsion and Power (AJCPP 2016), AJCPP2016-113.

Yagi, R., Yamauchi, T., Fujita, H., Kajihara, K., Tahara, H., Takada, K. and Ikeda, T., (2017) 'Research and Development of the Osaka Institute of Technology 2nd PROITERES Nano-Satellite with High-Power Pulsed Plasma Thrusters for Powered Flight' 31th International Symposium on Space Technology and Science. ISTS-2017-b-150