On-Orbit Thermal Analysis of High Voltage Technology Demonstration Satellite, HORYU-II

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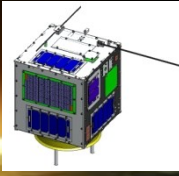
Background/ Objectives



	Large satellite	Nano-satellite
Maker	Country, Company	Company, University etc
Mass	>*O*(100kg)	Less than 50kg
Power	High	Low
Cost	Expensive	Cheap
Due date	long	short

Affected easily by the external environment.

It consists of COTS*.

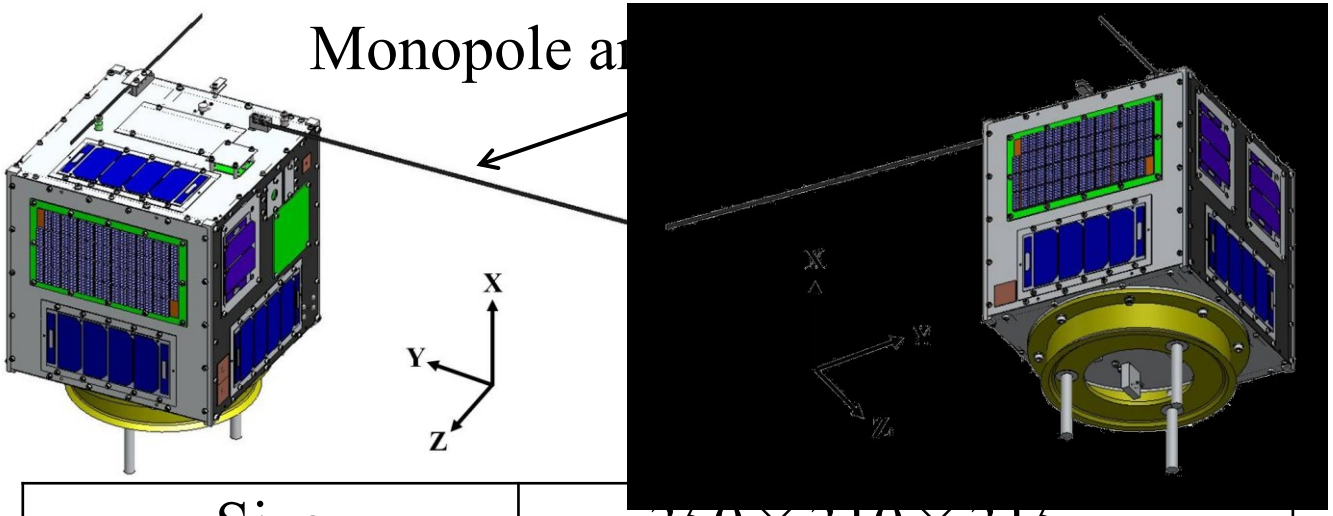
The acceptance temperature range of COTS* is narrow.

The thermal control of the whole system is necessary.

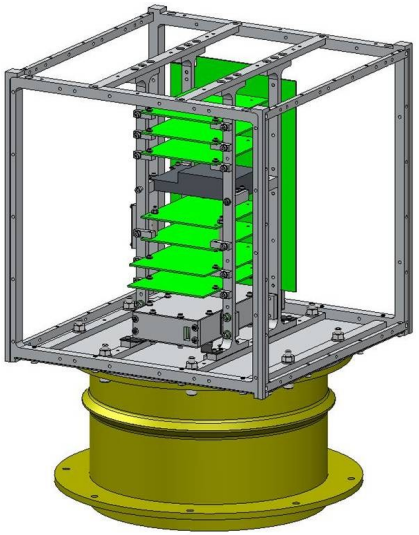
Examination of the thermal design of HORYU-II

*COTS : Commercial Off The Shelf

HORYU-II



Size	350×310×315mm
Mass	7.1kg
Design Life Time	1 year
Orbit	Sun-synchronous polar orbit
Altitude	670km



Centered pillar type

Main mission : 300V photovoltaic power generation

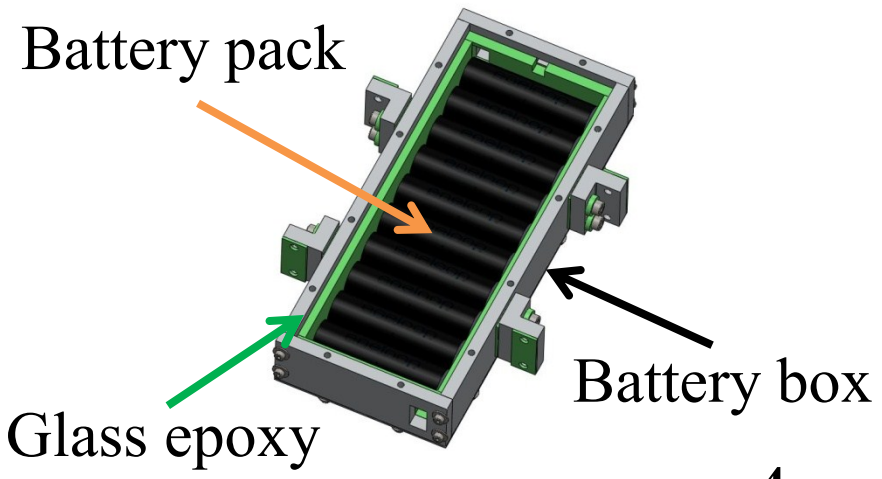
⇨ Already succeeded in the mission.

The highest photovoltaic power generation in the world

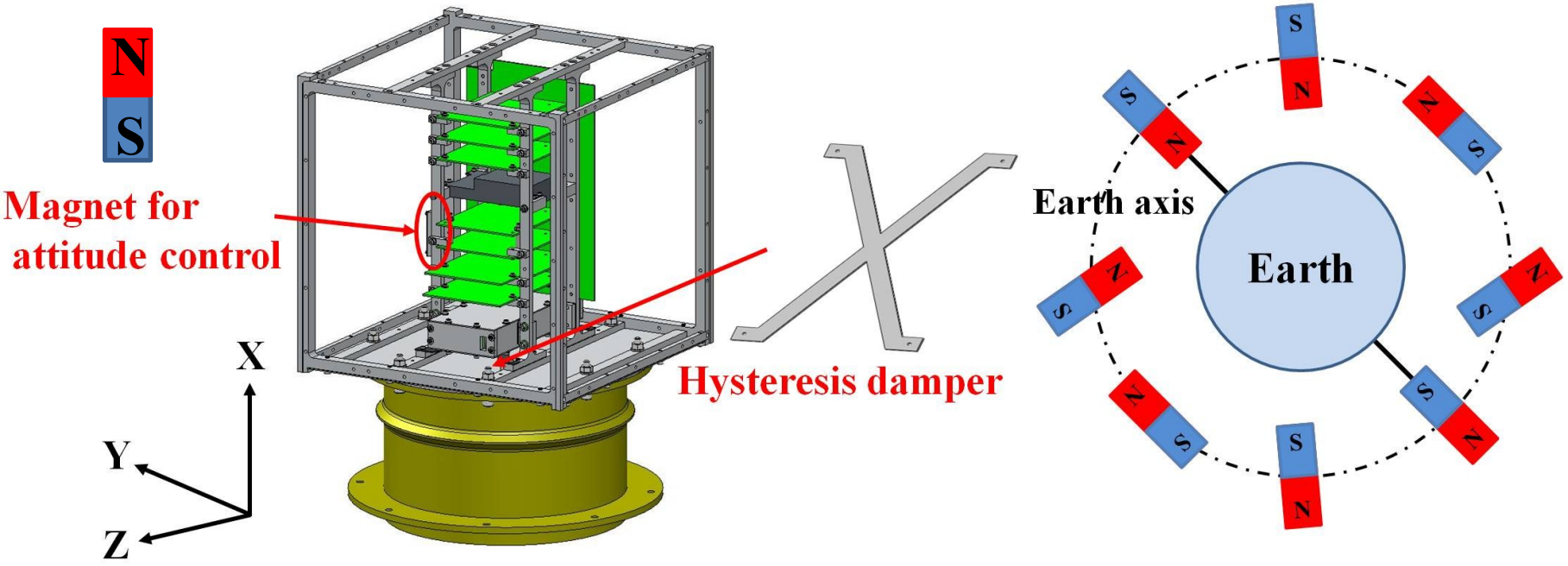
Thermal design

- HORYU-II is fundamentally a passive thermal control.
  - ±Y surfaces : Z306(Black paint) - α=0.96, ε=0.87
    ⇨ Heat exchange
  - ±X, Z surfaces : Arojin treatment - α=0.1, ε=0.03
    ⇨ Heat insulation
- The inside of the battery box is insulated by a glass epoxy
- Battery heater

System	Permissive temperature range
OBC	-20 ~ +70 °C
COM	-10 ~ +60 °C
Battery	0 ~ +45 °C
Mission	-15 ~ +50 °C



Attitude control

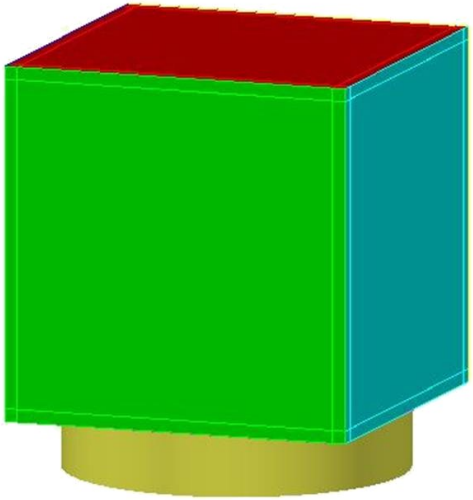


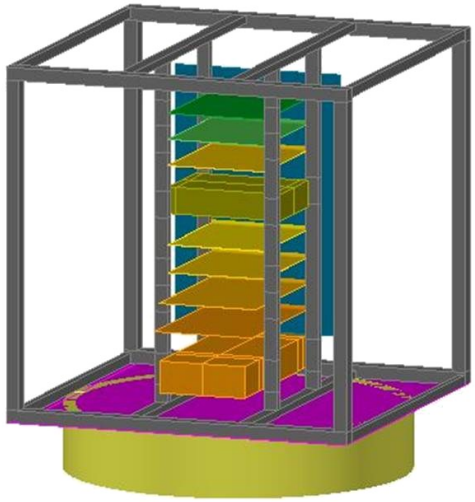
- HORYU-II is controlled only by magnetic field alignment
- A hysteresis dumper attenuates libration motion

By analysis,

two full rotations per one orbit around the Earth.

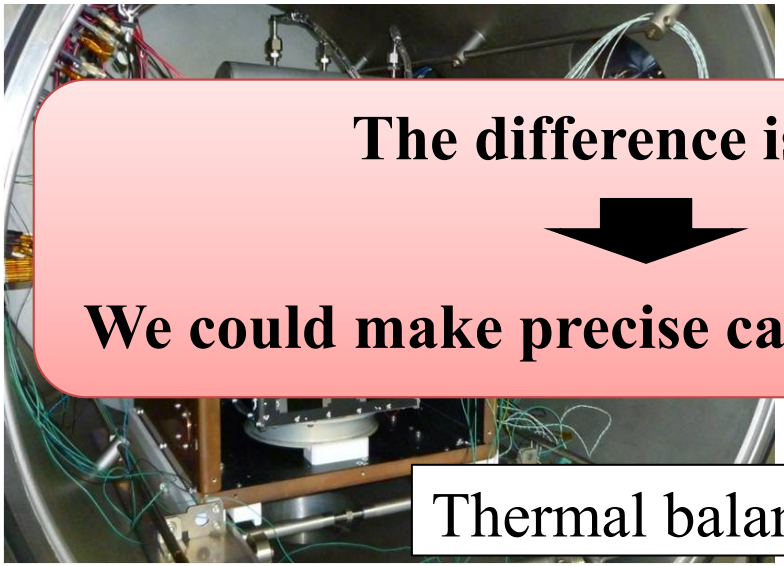
Thermal Mathematical Model





Thermal Desktop
(built in AutoCAD)

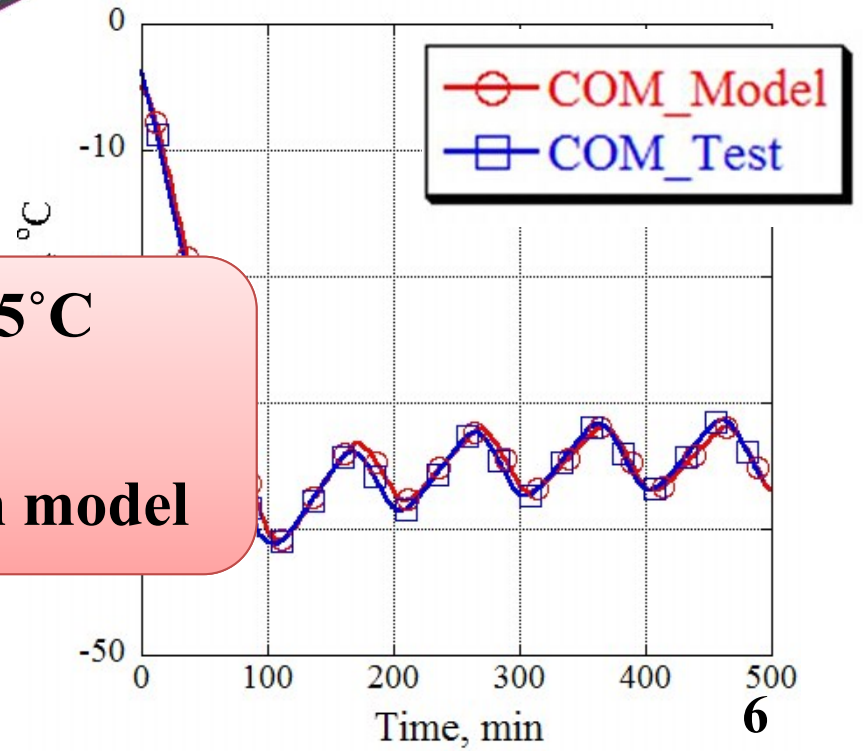
- Total Node： 127 Nodes
- Model is the same size as HORYU-II



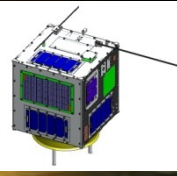
Thermal balance test

The difference is within 5˚C

We could make precise calculation model



Thermal Analysis Result



Uncertain factors
- Space environment
- Attitude(Rotation speed)

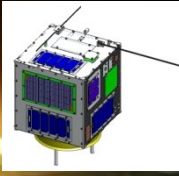
→ The worst case analysis

Worst Cold : the sunlight hardly enters ±Y surfaces.
Worst Hot : the sunlight mostly enters ±Y surfaces.

Analysis result

	Worst Cold (°C)		Worst Hot (°C)	
	Min.	Max.	Min.	Max.
External panel	-30	24	-14	53
Internal pole	-4.5	5	15	29
COM	-3	5.5	17	29
Battery	1.9	2.4	23	24

Telemetry Data



Data sampling period : 10min(600sec)

Orbital period of HORYU-II : 98min

We can get about 10 data per orbit.

This sampling rate was not enough to calculate the satellite attitude

We tried to determine the attitude from the orbit data of temperature changes.

- External panels – unstable temperature change
- Inside – stable temperature change

We focused on the temperature of COM* and tried to match the model calculation temperature with the on-orbit temperature.

*COM : communications (RF radio)

Gyro Sensor

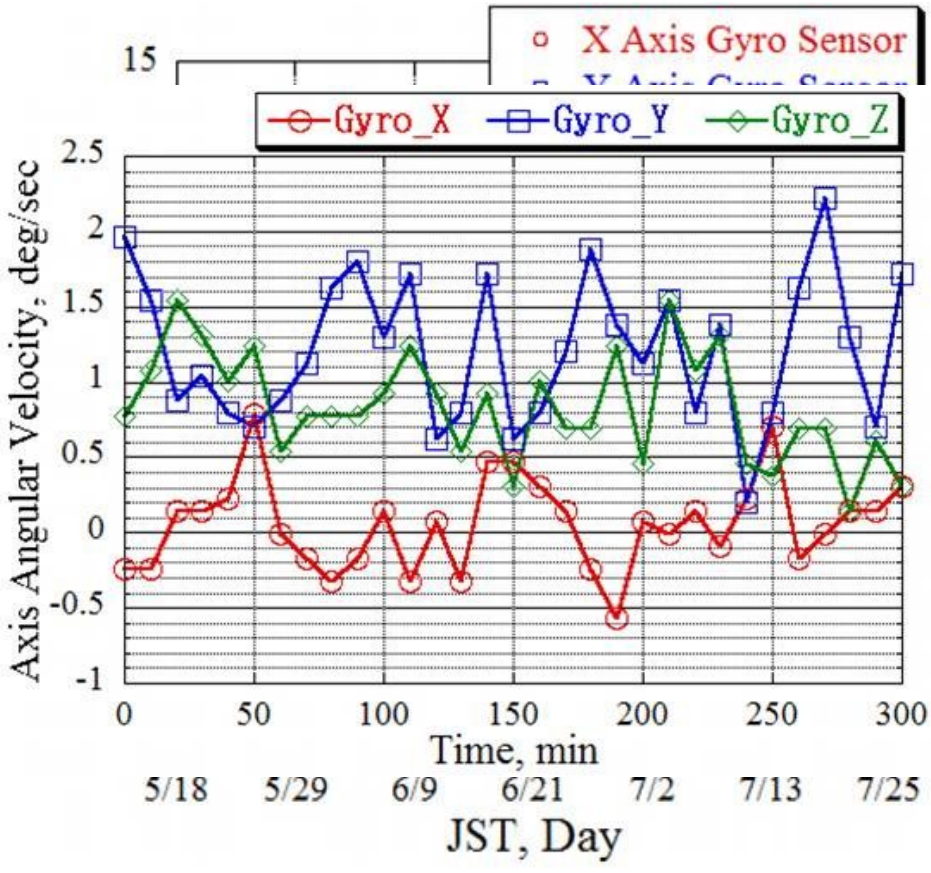
Immediately after the separation
more than 10 deg/sec

the hysteresis dumper and the long monopole antenna attenuated the rotations.

On July 25, 2012

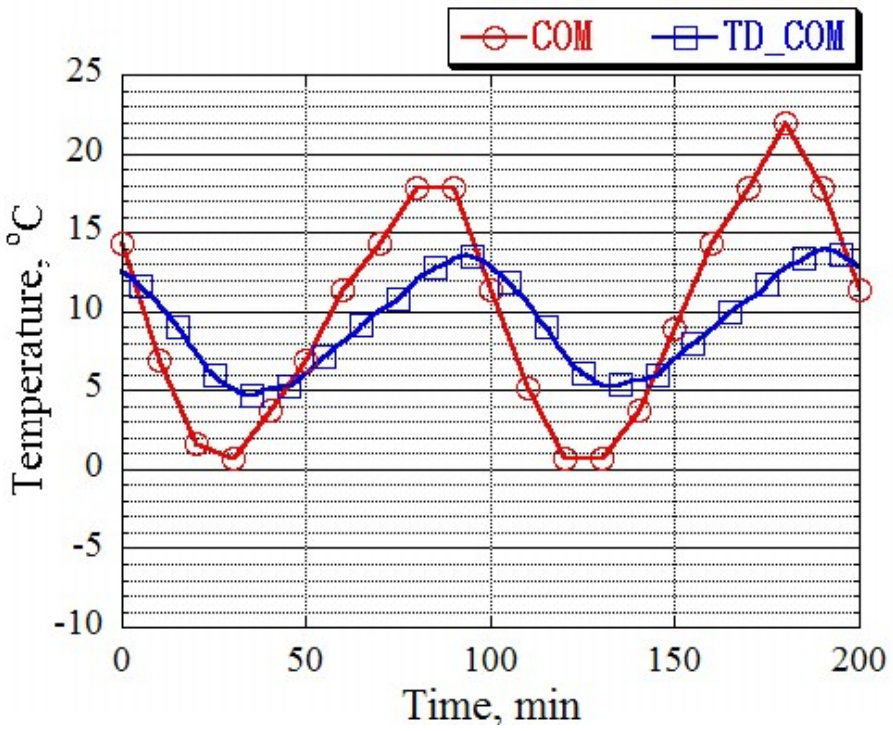
A rotation of HORYU-II seems to be stable.

Axis	Root Mean Square
X	0.38 deg/sec
Y	1.36 deg/sec
Z	1.04 deg/sec

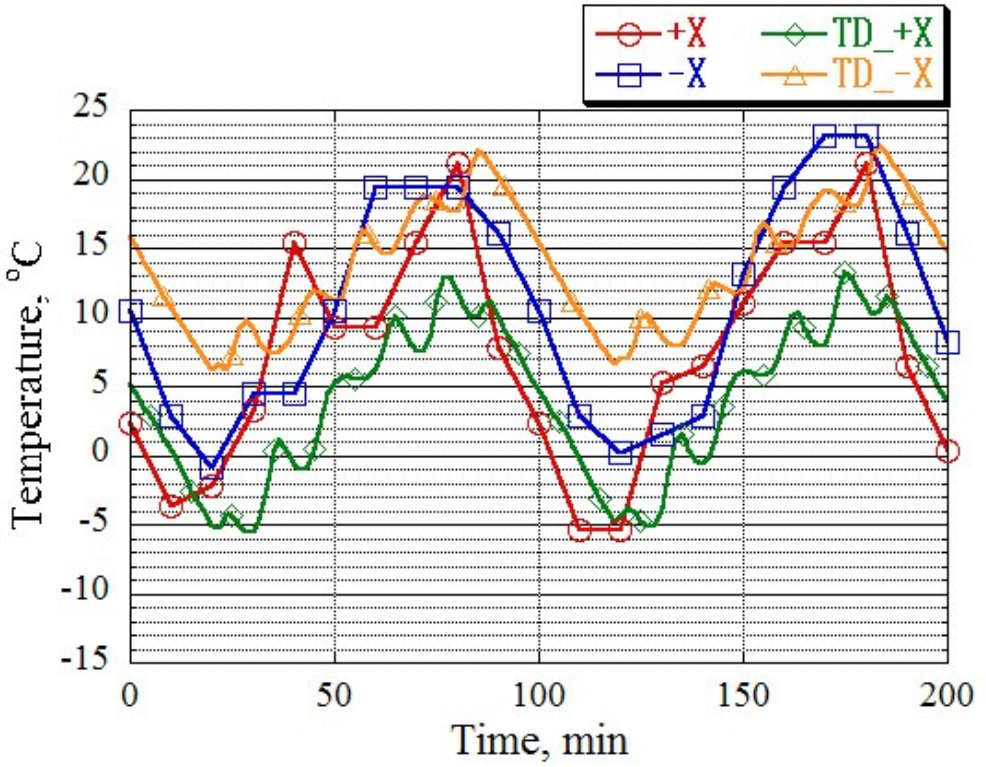


Analysis result

Temperature of COM



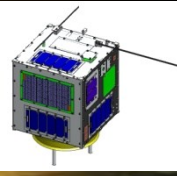
Temperature of X panels



The variation of temperature change given by TD is narrower than the on-orbit data.

*TD : Thermal Desktop

Parametric analysis

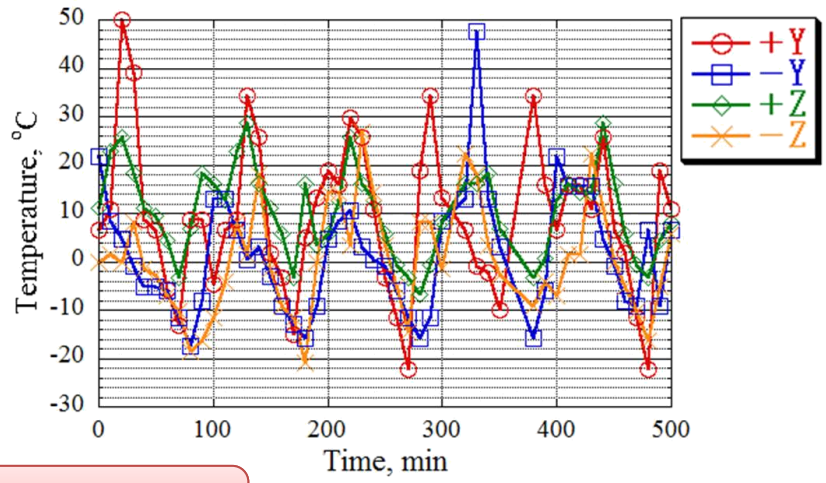


Angular Velocity (deg/sec)			COM (°C)		+X surface (°C)		−X surface (°C)	
X Axis	Y Axis	Z Axis	Min.	Max.	Min.	Max.	Min.	Max.
0.38	1.36	1.04	6	14	-5	13	7	22
0.38	2.36	1.04	6.2	14.7	-4	14	8	23
0.38	1.36	2.04	5.5	14.8	-4	16	6	21
0.38	2.36	2.04	6	15.2	-4	16	6	22
0.38	1.36	2.5	6.3	15	-4	14	7	23.5
0	1.36	1.04	6.5	15.5	-4	15	8	24

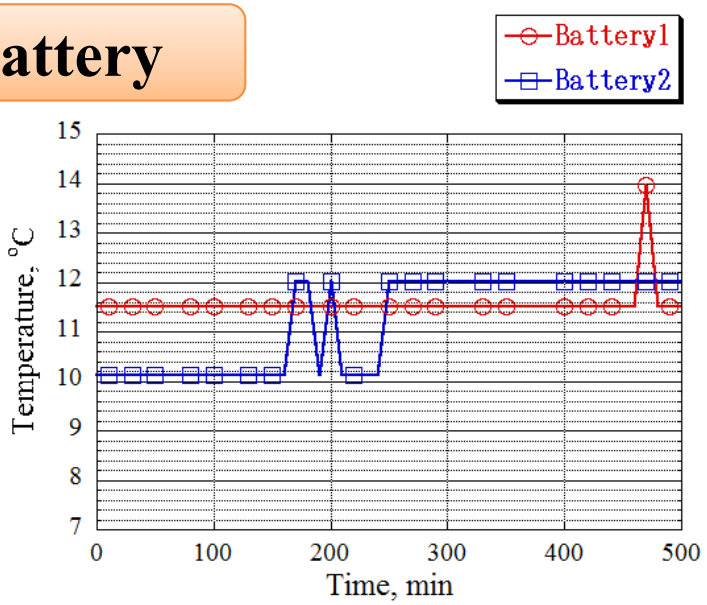
Too many possible combinations of rotating speed in 3 axes. Therefore, defining a unique combination of rotating speed is difficult from the information obtained at present.

On-orbit temperature data

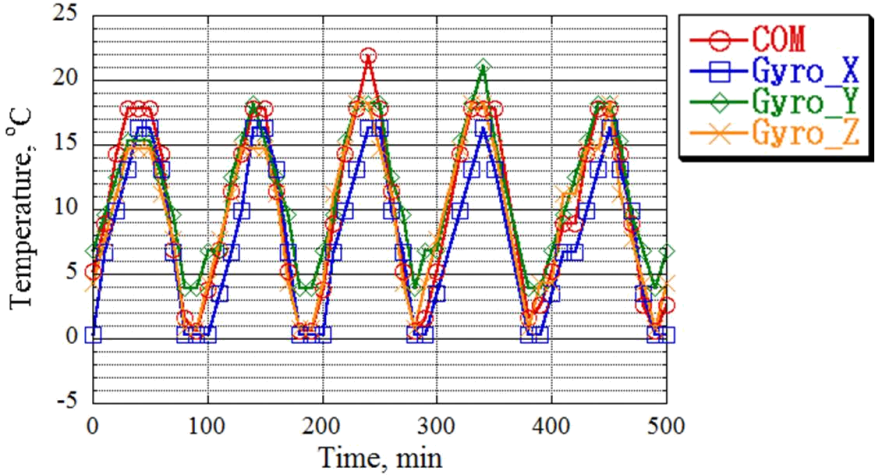
External panel



Battery

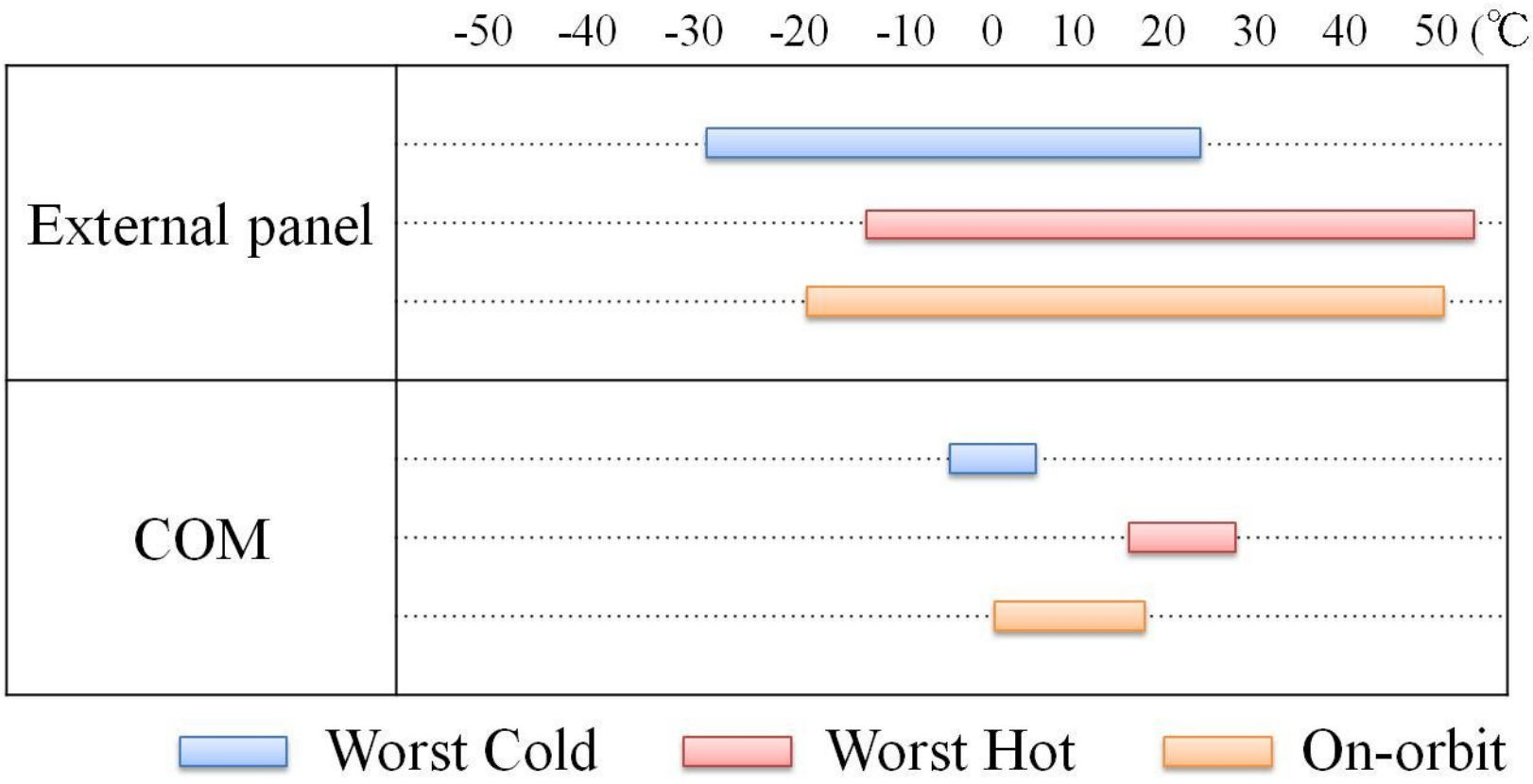


Inside



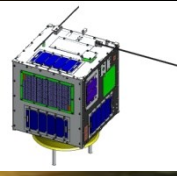
External panel	: **-22～+50**°C
Inside	: **0～+22**°C
Battery	: **+10～+12**°C

Compared with On-orbit data



The on-orbit temperature was within the temperature range we predicted in the thermal analysis. The thermal design of HORYU-II was appropriate.

Conclusions and Future tasks



- Conclusions

✓ We could conduct thermal analysis by Thermal Desktop.

✓ We could confirm a soundness of the thermal design of HORYU-II from the on-orbit temperature data.

- Future tasks

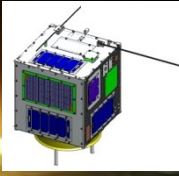
✓ Specifying the attitude of HORYU-II under the influence of magnetic field.

✓ Check the influence of the long monopole antenna on the rotation attenuation.

Thank you for your attention.

Appendix

Thermal environment



Sunlight

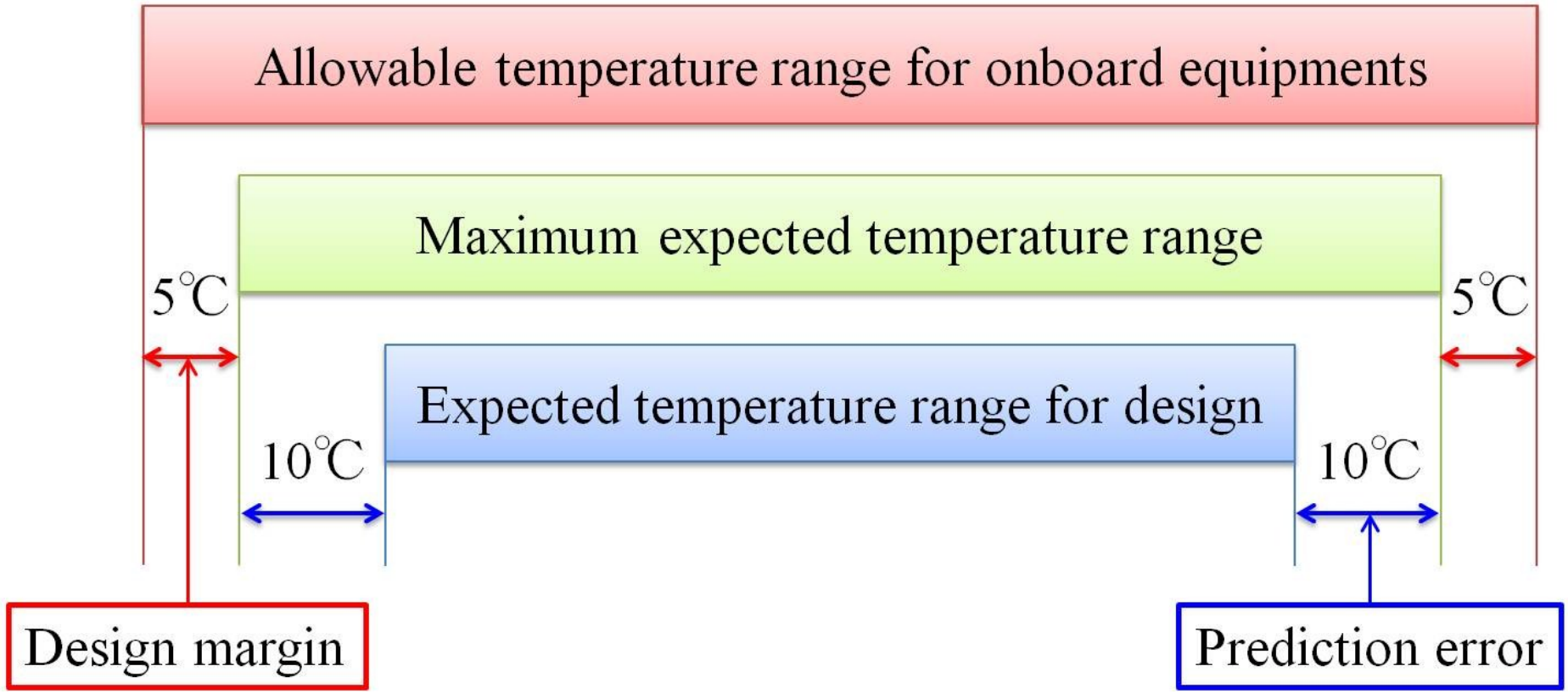
Space : −270℃

Eclipse

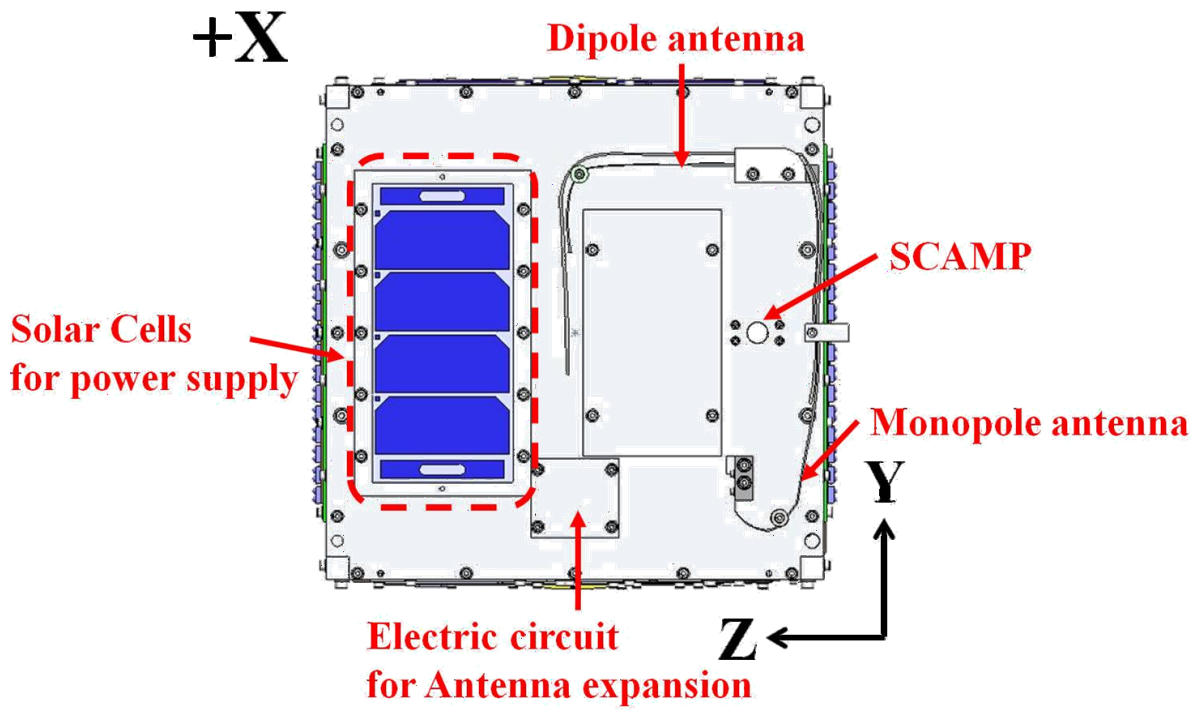
Temperature of satellite

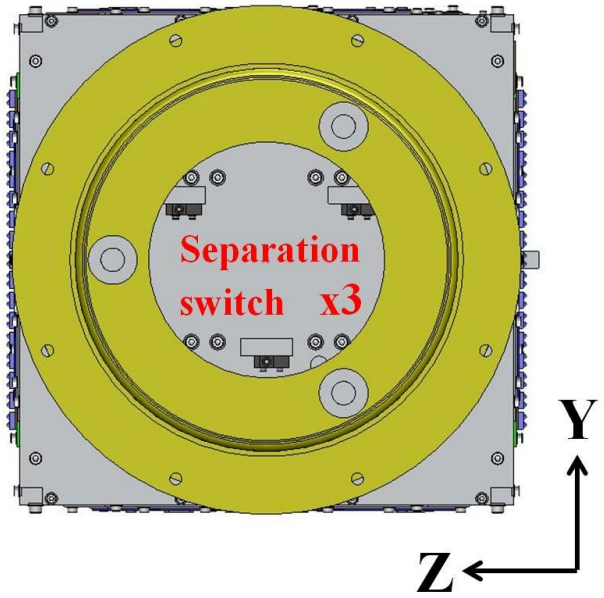
More than＋100℃ ⟷ **Less than−100℃**

Thermal design



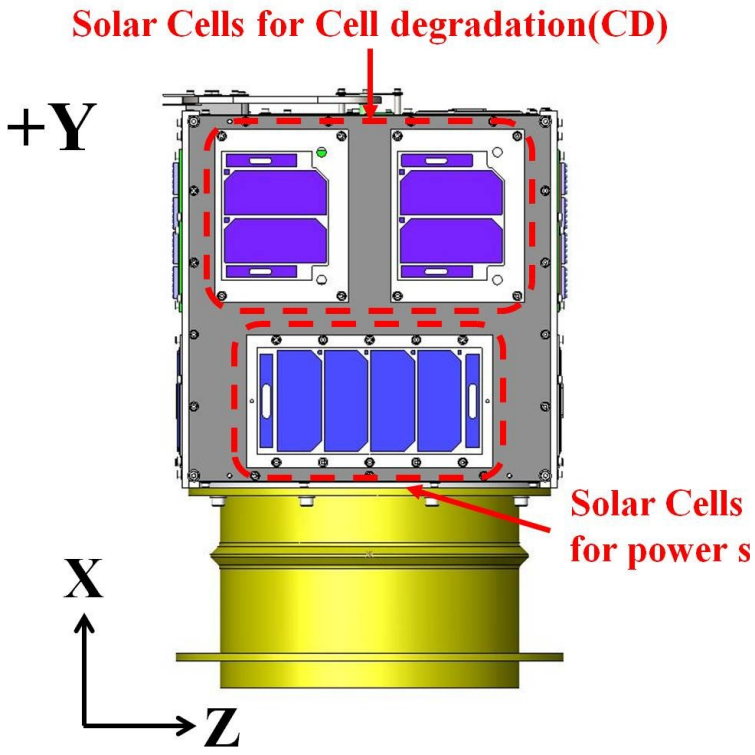
HORYU-II

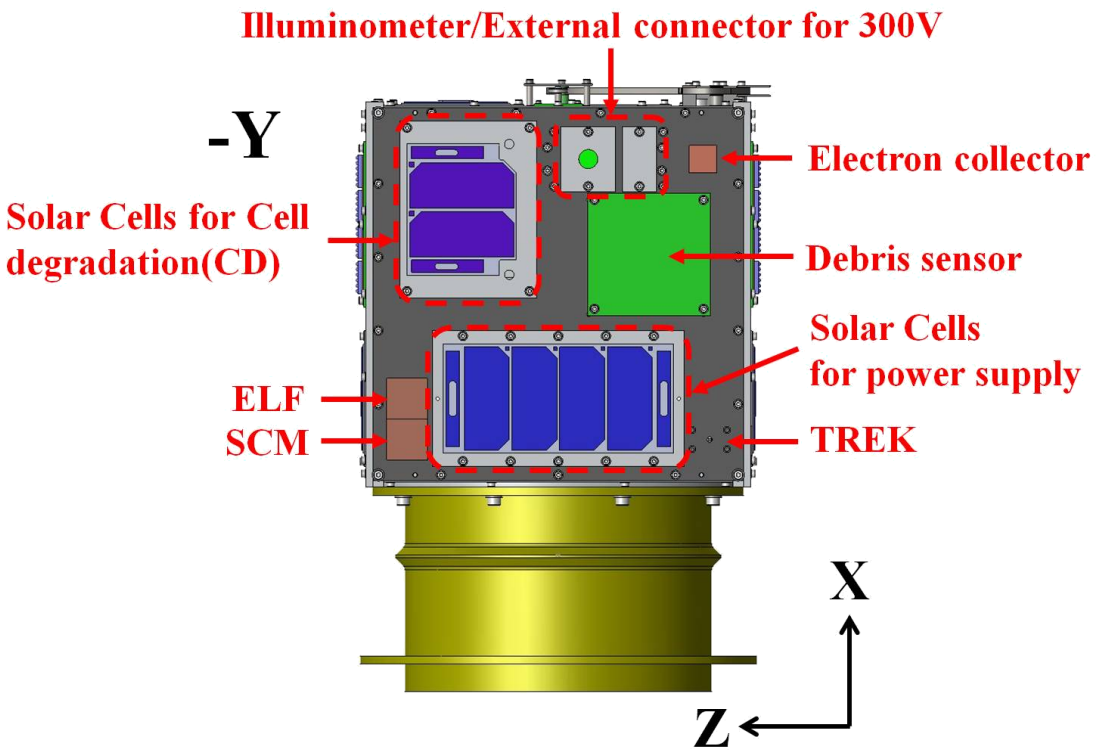

+X
Dipole antenna
SCAMP
Solar Cells
for power supply
Monopole antenna
Y
Z
Electric circuit
for Antenna expansion


Separation
switch x3
Y
Z

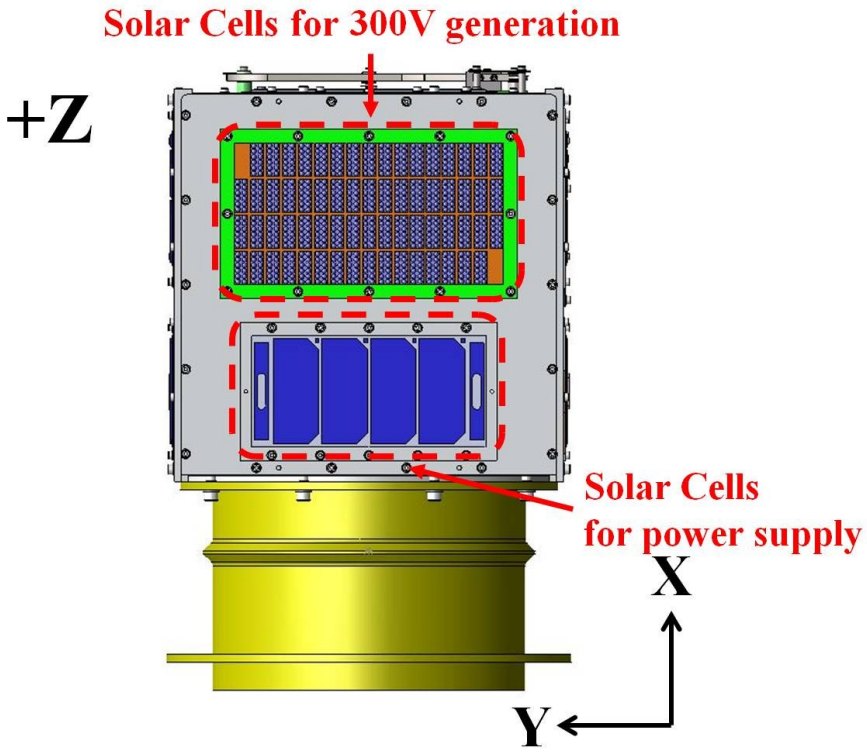
HORYU-II

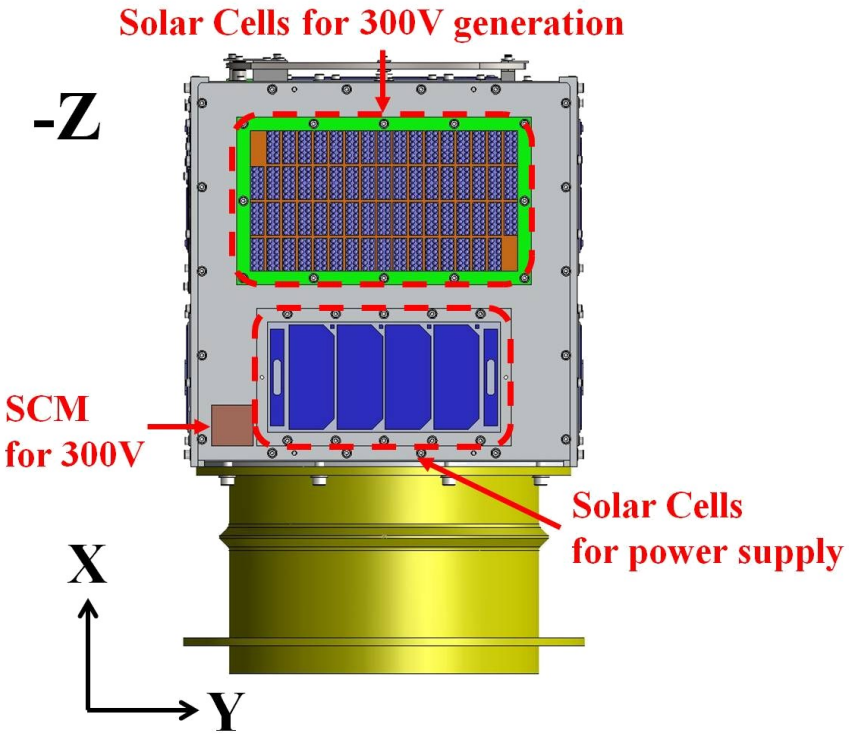
KIT Satellite Horyu2


Solar Cells for Cell degradation(CD)
+Y
Solar Cells
for power s
X
Z

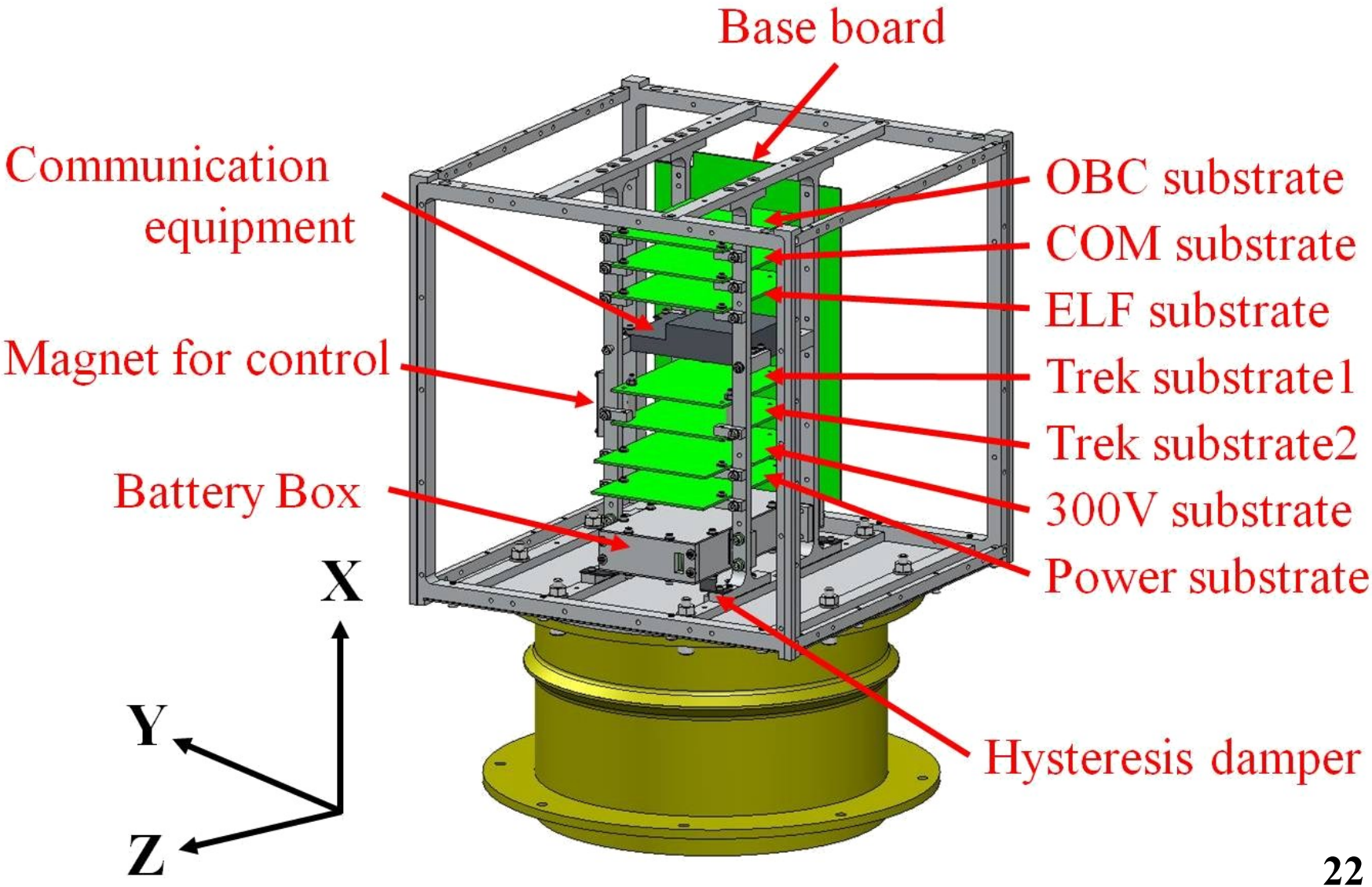

Illuminometer/External connector for 300V
-Y
Solar Cells for Cell
degradation(CD)
Electron collector
Debris sensor
Solar Cells
for power supply
ELF
SCM
TREK
X
Z

HOYRU-II


Solar Cells for 300V generation
+Z
Solar Cells
for power supply
X
Y


Solar Cells for 300V generation
-Z
SCM
for 300V
Solar Cells
for power supply
X
Y

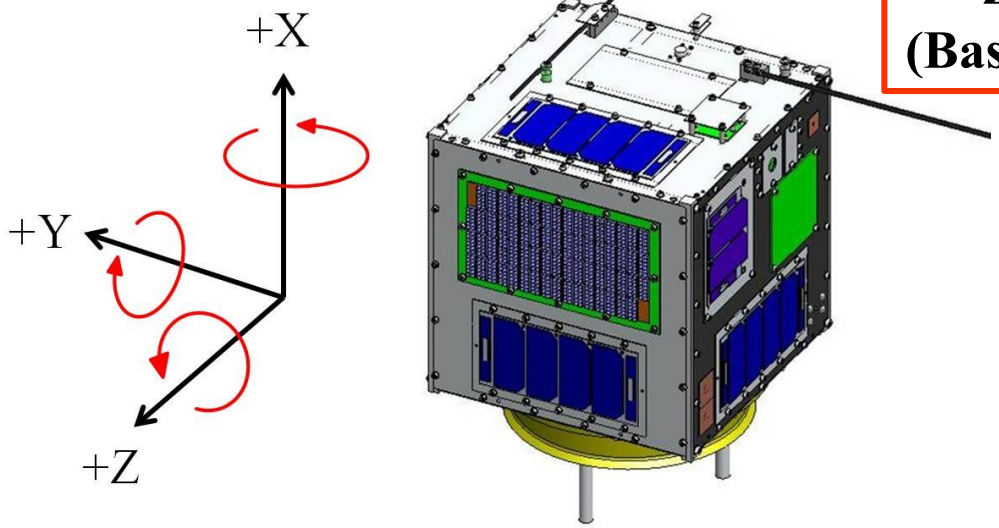
HORYU-II

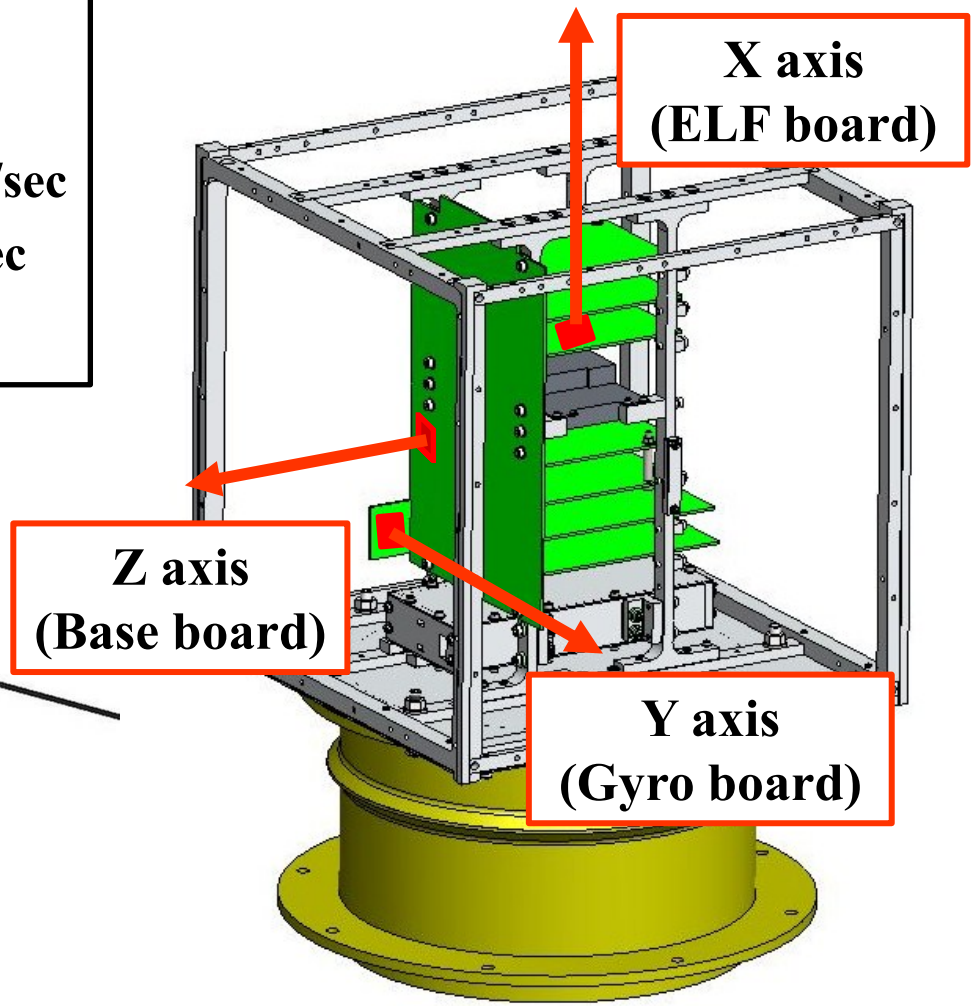

Base board
Communication equipment
Magnet for control
Battery Box
OBC substrate
COM substrate
ELF substrate
Trek substrate1
Trek substrate2
300V substrate
Power substrate
Hysteresis damper
X
Y
Z

Gyro Sensor

- Model number：ADXRS614
- 1 axis angle velocity measurement
- Measurement range：Max±30deg/sec
- Measurement accuracy ：±1deg/sec
- Built-in temperature sensor

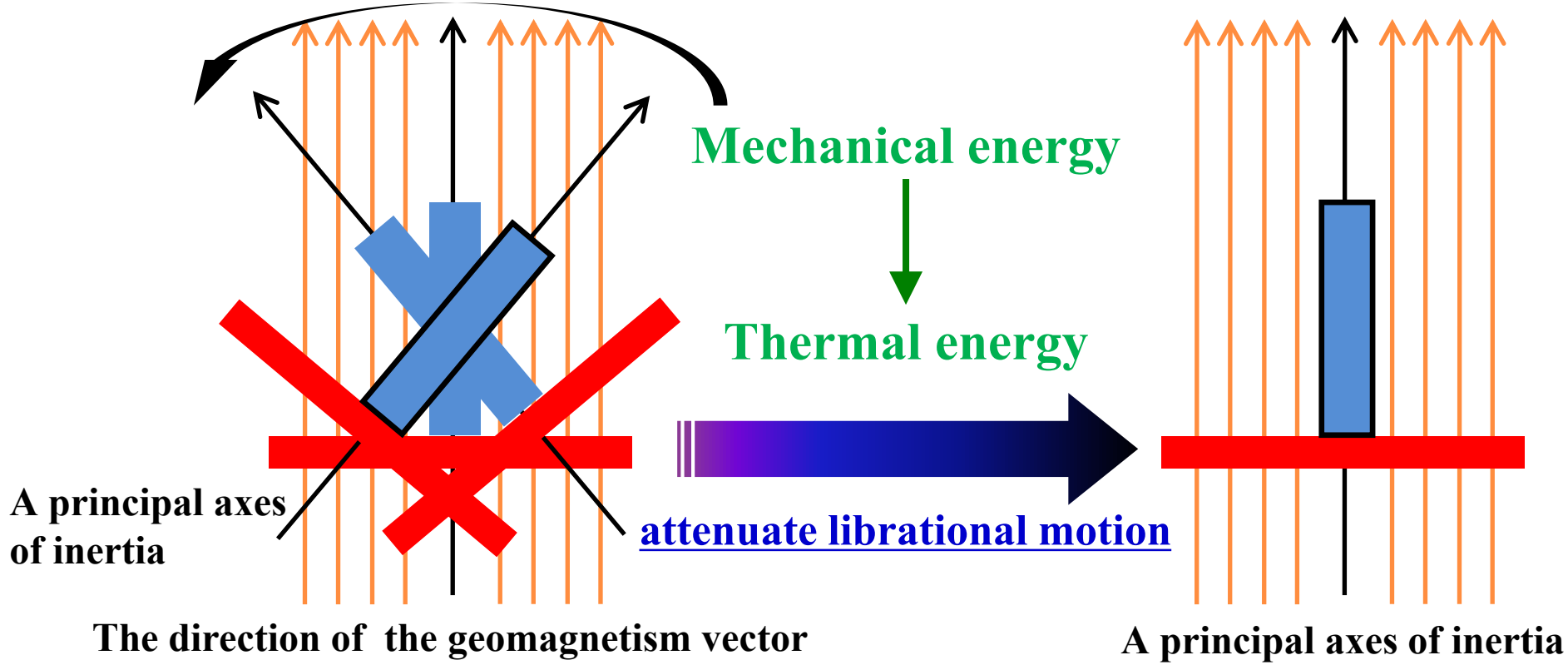
Direction of the arrow
= Positive rotation





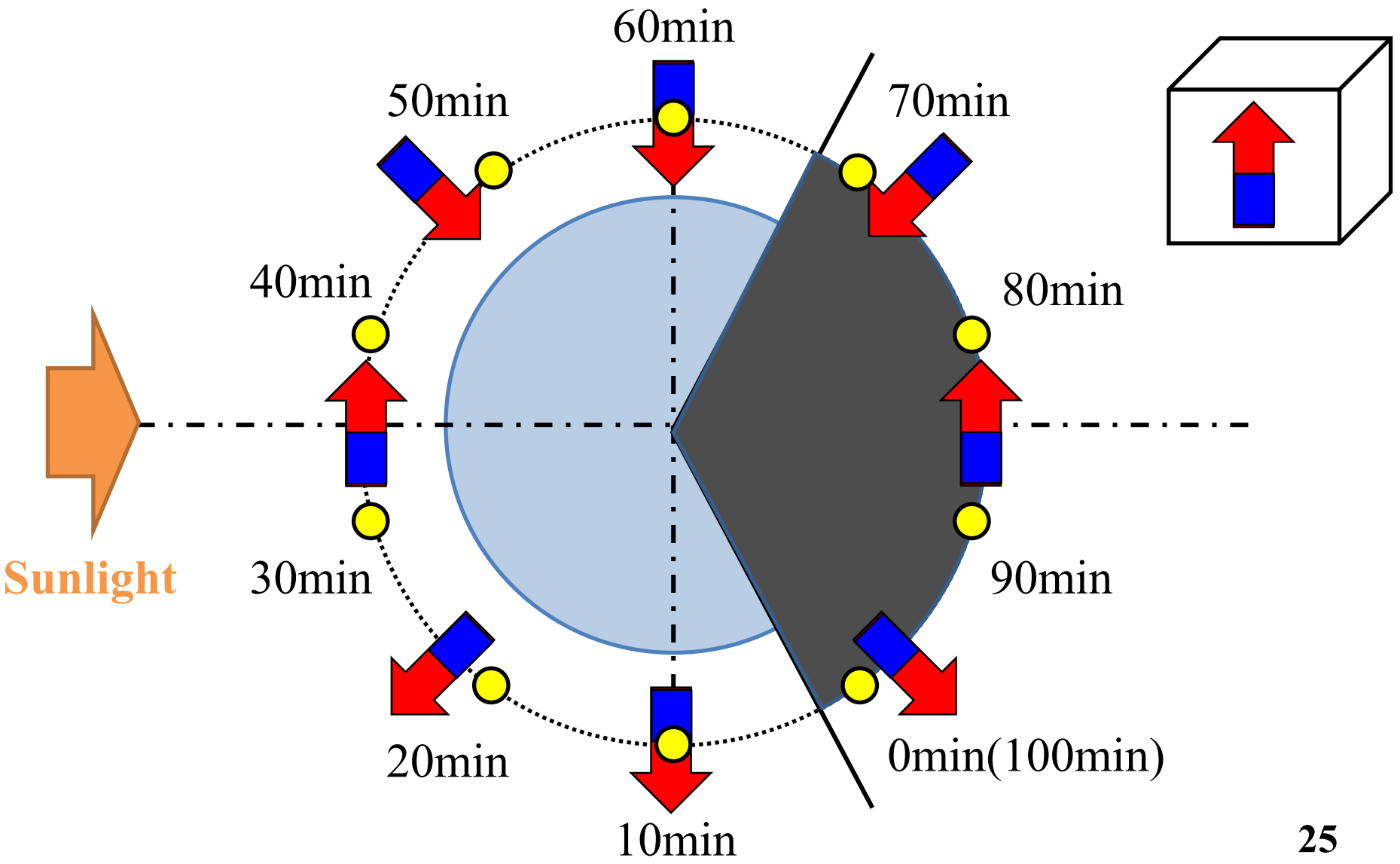
Hysteresis dumper

The principle to attenuate librational motion



HORYU-II perform libration motion along the geomagnetism

Control of magnetic field alignment

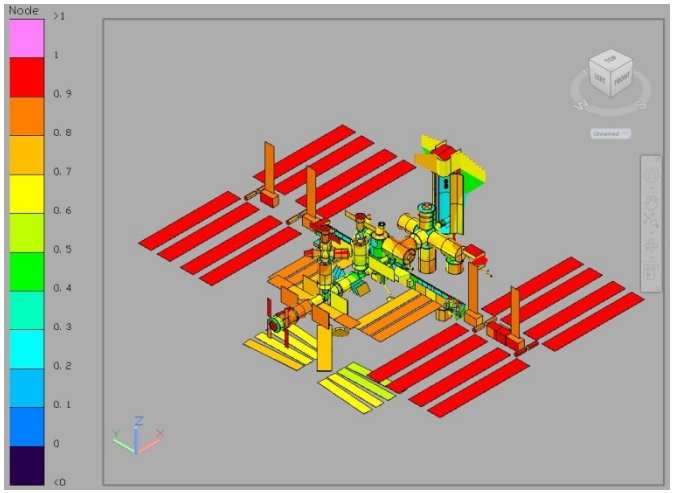


Thermal Analysis Software

Thermal Desktop®

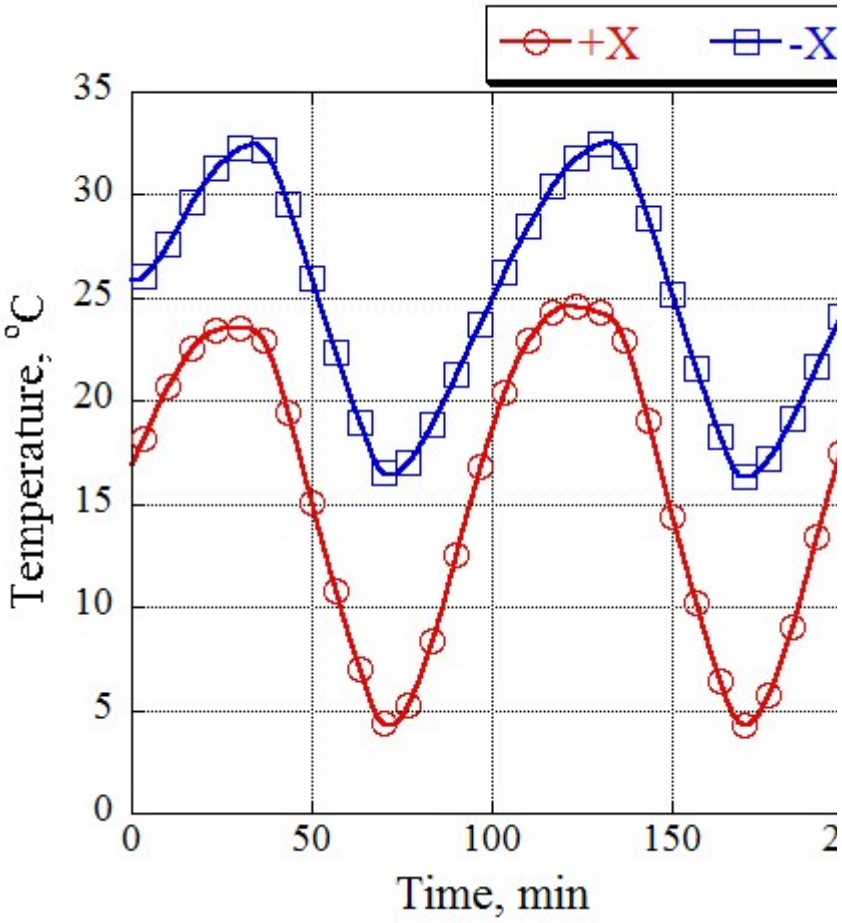
（Cullimore and Ring Technologies corporation）

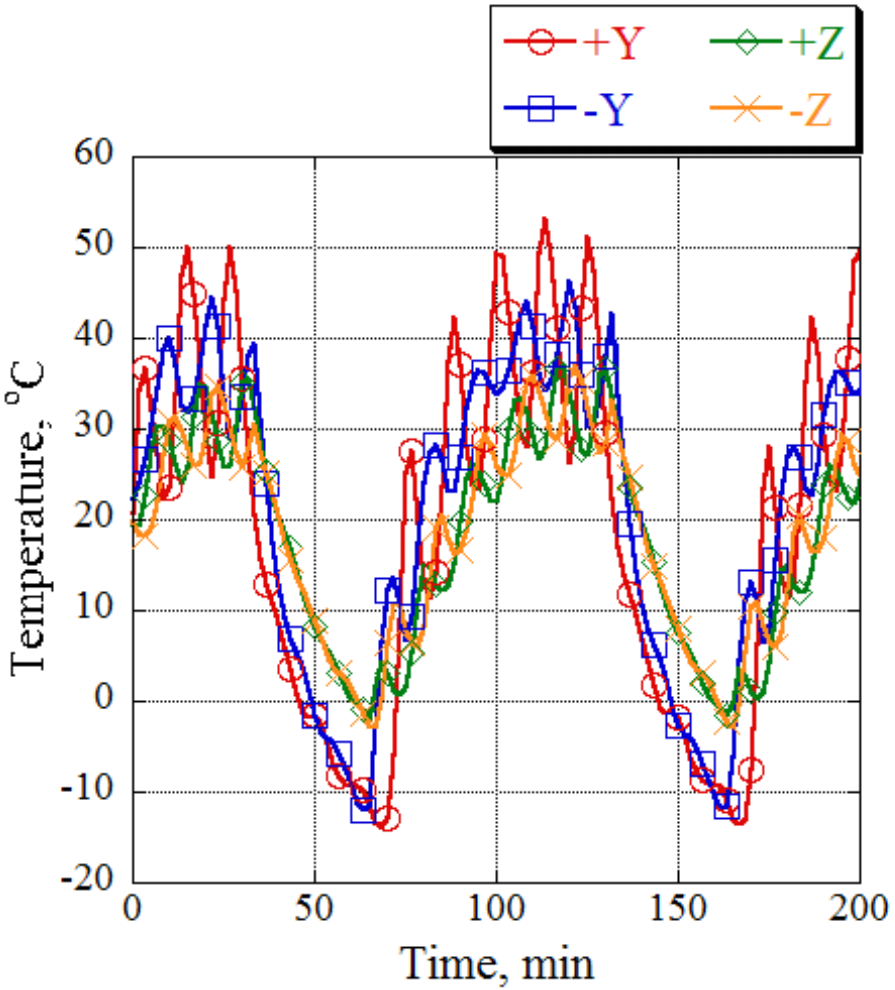
- ■With AutoCAD making a Thermal Mathematical Model
- ■Making thermal networks
- ■Steady-state/Transient analysis
  （Parametric analysis）



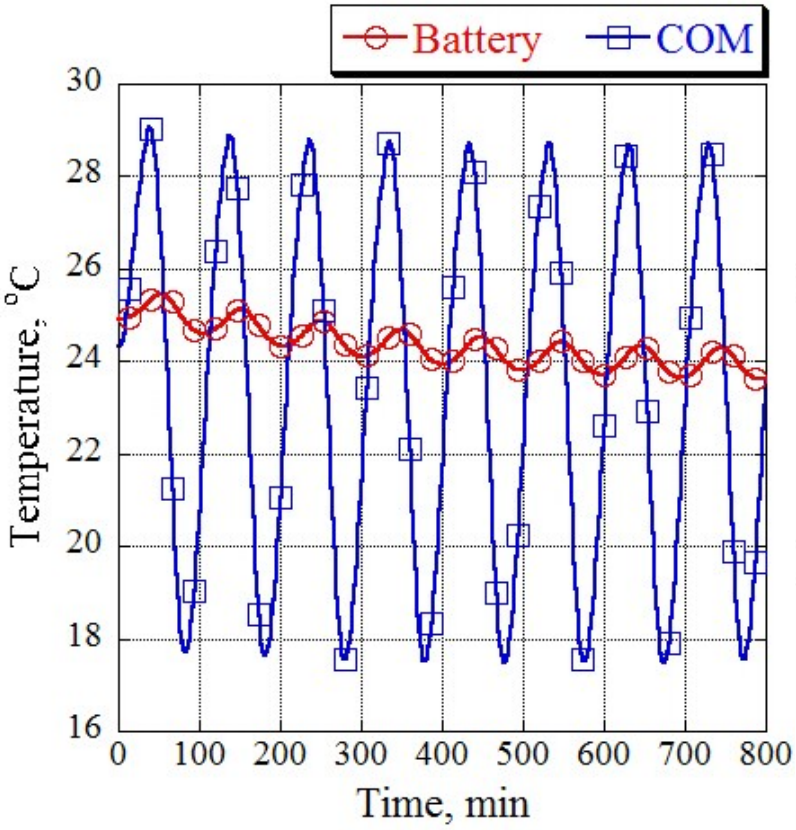
As a thermal design and a thermal analysis tool, Thermal Desktop is used by NASA development projects and so reliable.

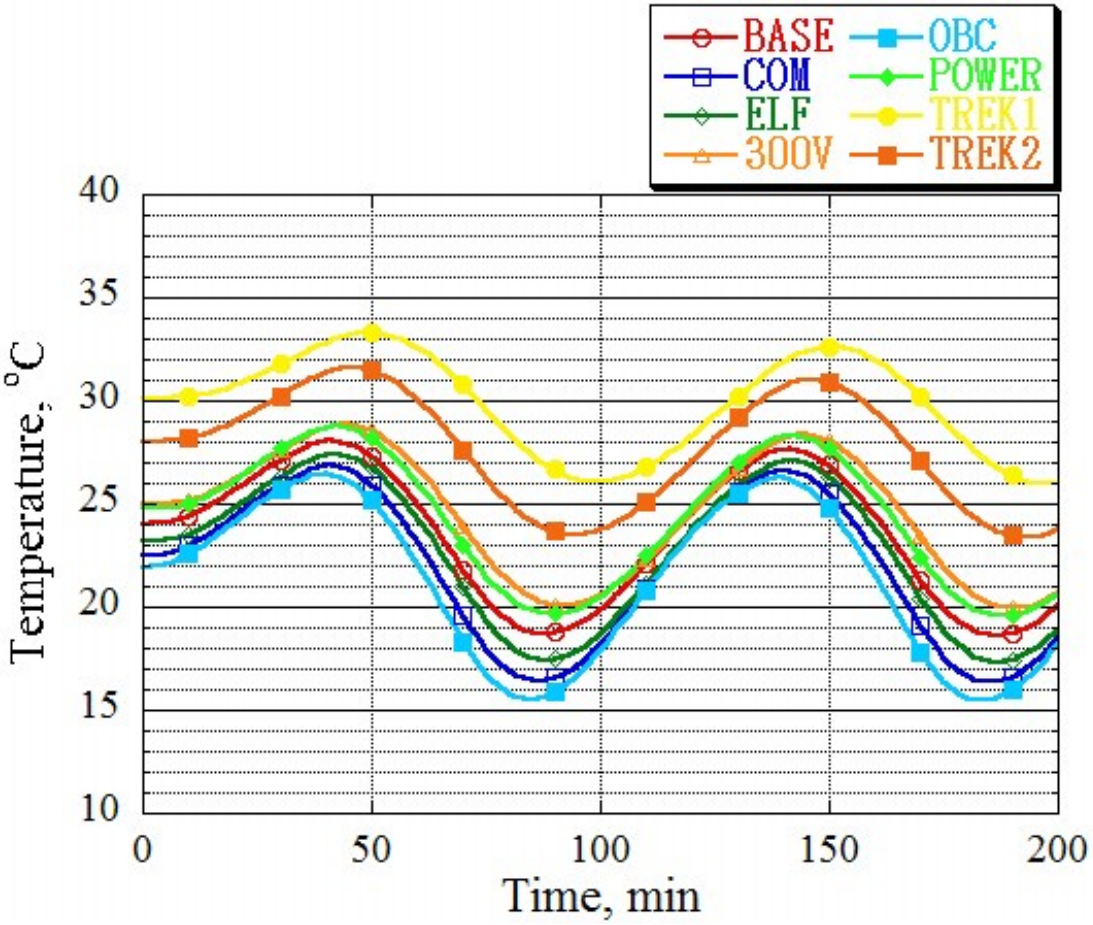
Worst Hot – Analysis result



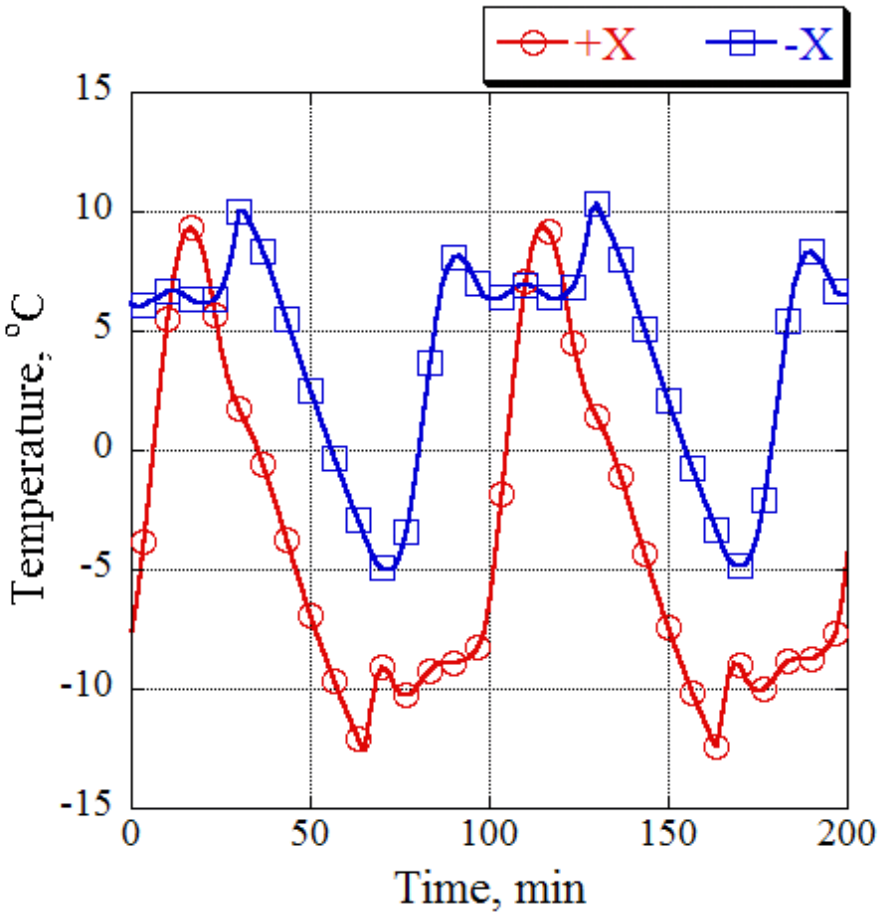


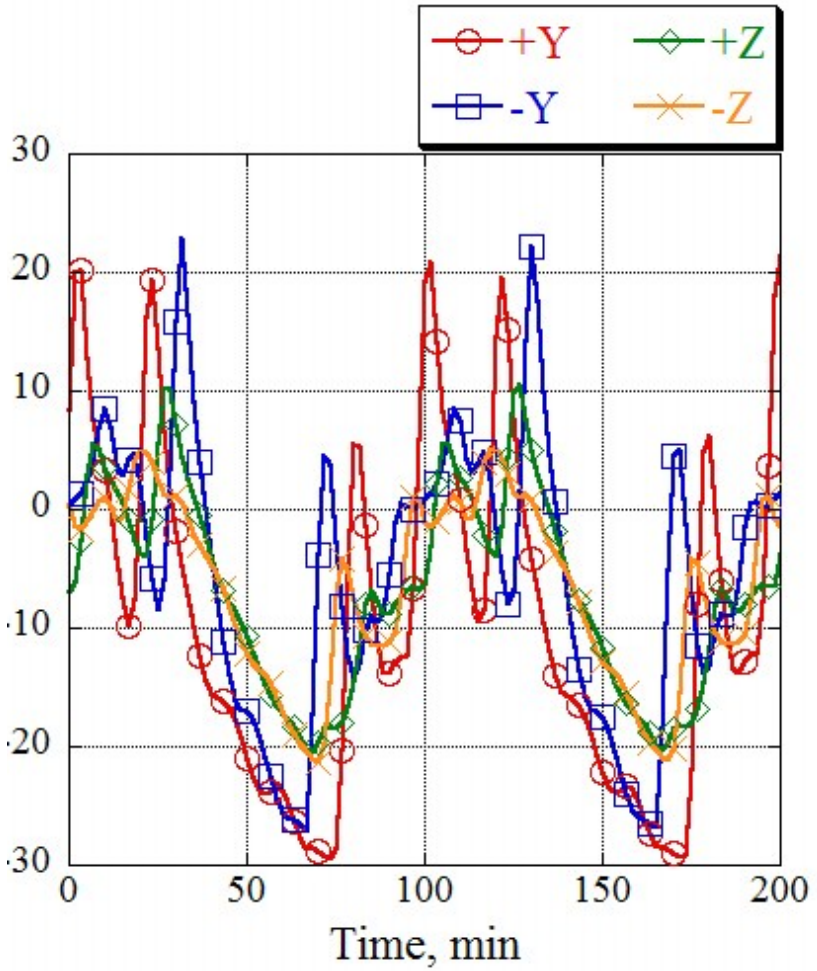
Worst Hot – Analysis result



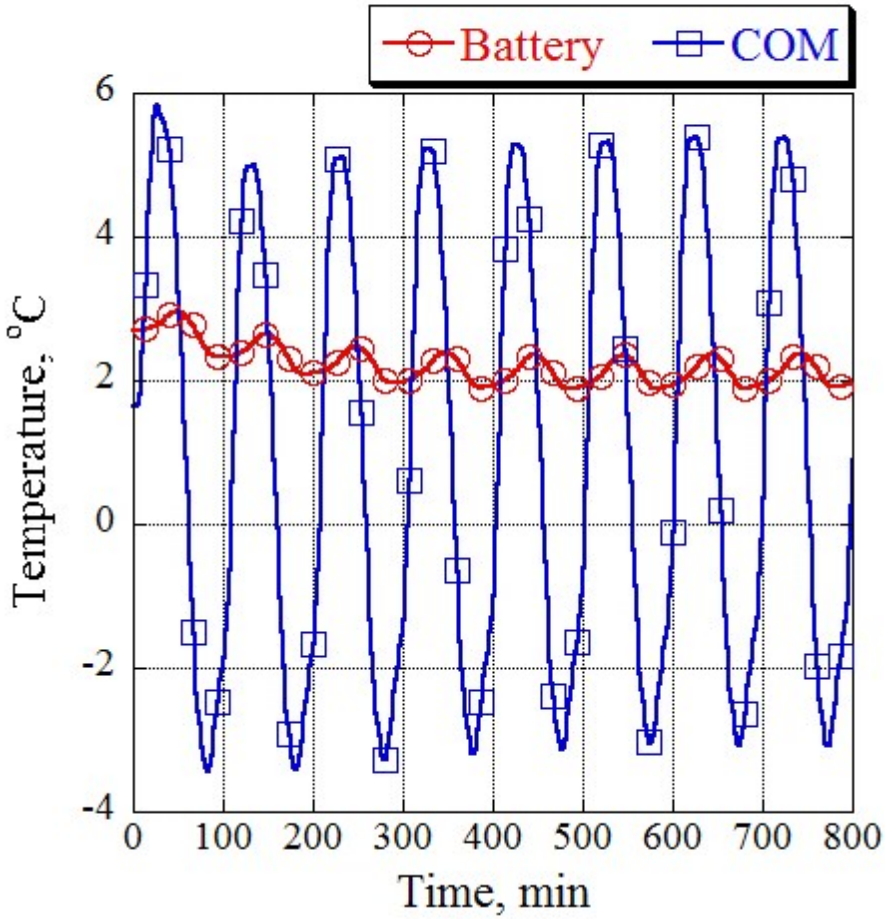


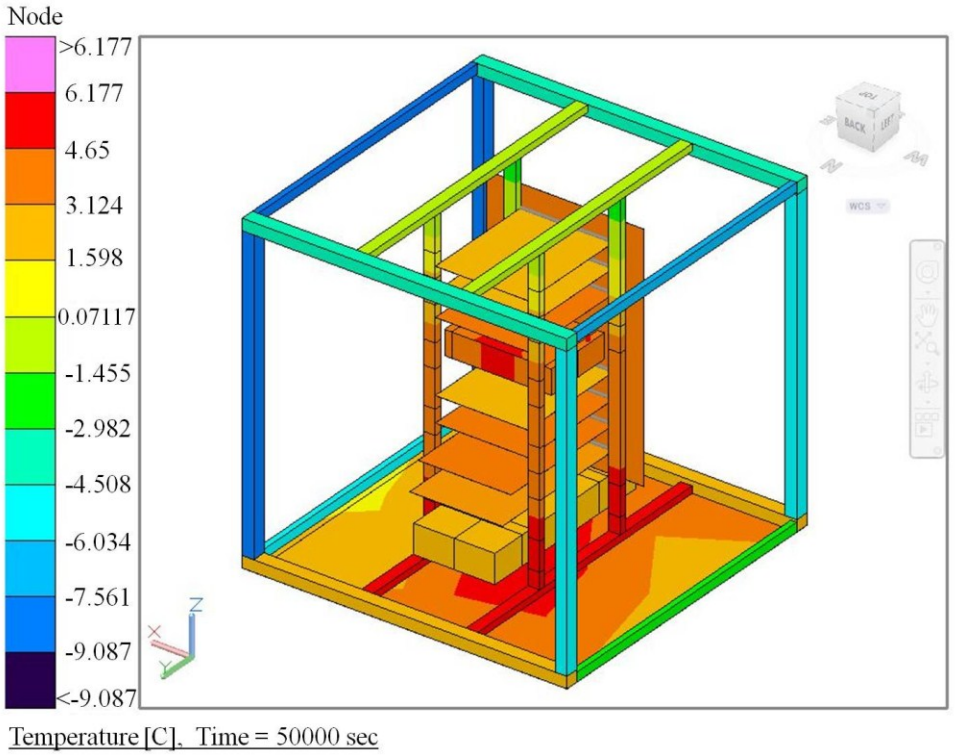
Worst Cold – Analysis result



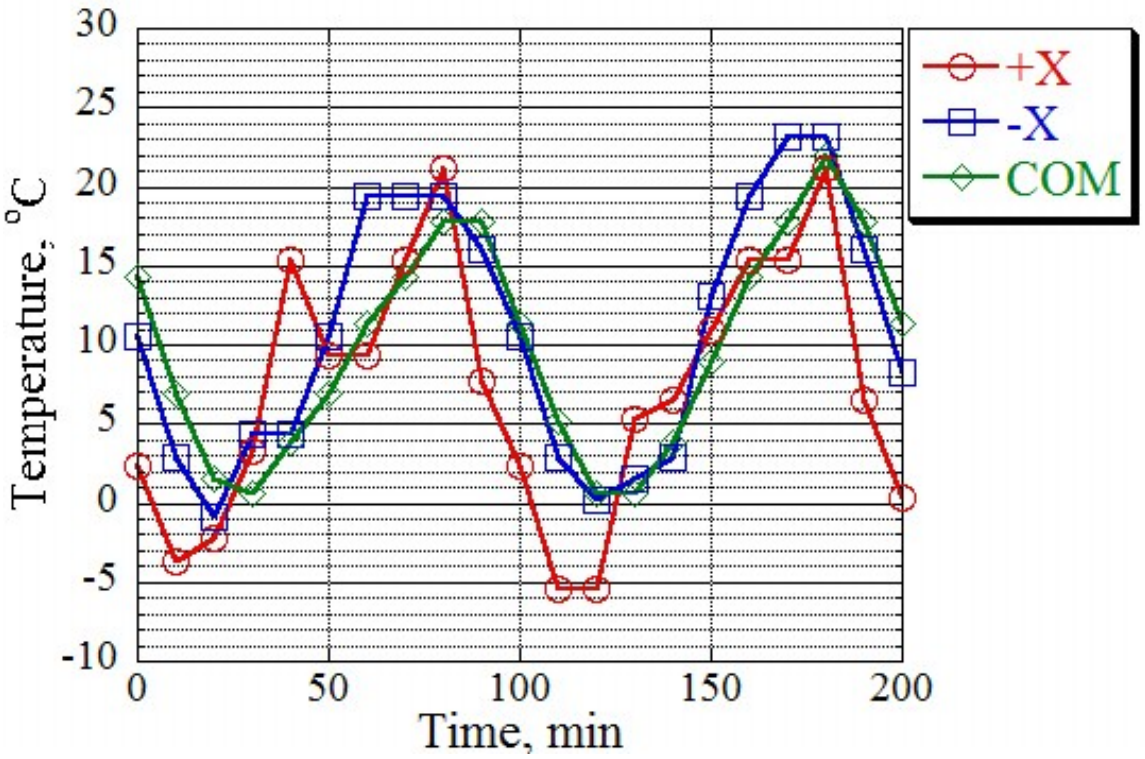


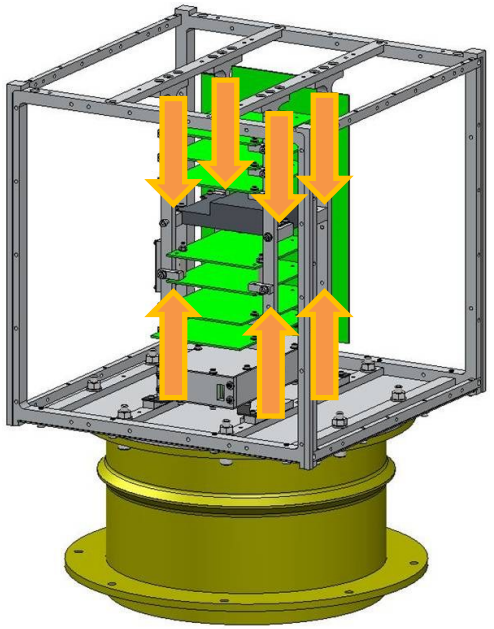
Worst Cold – Analysis result





Temperature relationship with COM and X panels





A temperature change of ±X panels transfers to the internal components by thermal conduction through center pillars.