Kyushu Institute of Technology
Laboratory of Spacecraft Environment Interaction Engineering

BIRDS-4
JOINT GLOBAL MULTI-NATION BIRDS SATELLITE PROJECT

FM Thermal Vacuum Test Procedure

BIRDS-4 Project

La SEINE

Date	Version Number	Writer	Annotations
2019/12/06	v1.0	Anibal Mendoza	First Draft

Contents

1. Introduction

1.1. General

The Thermal Vacuum Test (TVT) of the Engineering Model (FM) of BIRDS-4 satellite shall pass qualification requirements under vacuum conditions and temperature extremes which simulate predicted space environment.

1.2. Objectives

The following are the test objectives:

- Check and analyze various satellite point temperatures under extreme hot and cold conditions.
- Check and analyze functionality and operation of the satellite under the defined temperature range (extreme hot, extreme cold and middle temperature conditions).
- Check and analyze operation of battery heater and thermal monitors under the defined temperature range.

1.3. Scope

This document is applied to thermal vacuum test for BIRDS-4 FM using the “Space Chamber” at the Center for Nanosatellite Testing (CENT) at Kyutech.

2. Reference

Document number	Document description	Revision level or Release date
ISO/TC 20/SC 14 N 1004	Space systems - Design Qualification and Acceptance Tests of Small-scale Satellites and Units Seeking Low-cost and Fast-Delivery	2014/05/05
BIRDS-4 RAS	BIRDS-4 Project Requirement Allocation Sheet	Version 53 (2019/08/01)

3. Nomenclature

3.1. Acronyms

ADCS	Attitude Determination and Control System
COM-UHF TRX	UHF transceiver board
FM	Flight Model
EPS	Electric Power Subsystem
FAB	Front Access Board
GPS	Global Positioning System
GS	Ground Station
LN2	Liquid Nitrogen
MB1-MB2	Mission Board 1, 2
OBC	Onboard Computer
PCB	Printed Circuit Board
RAB	Rear Access Board
RBF	Remove-Before-Flight
SP	Solar Panel
TC	Thermocouple
TVT	Thermal Vacuum Test

3.2. Symbols

°C	Degree Celsius
Ω	Ohm (resistance value)
W	Watt
Pa	Pascal

4. Test Purpose

4.1. Overall test purpose

- Measure temperatures at different satellite points under extreme hot and cold conditions.
- Check functionality and operation of the satellite under defined temperature range (extreme hot, extreme cold and middle temperature conditions).
- Check operation of battery heater and thermal monitors under defined temperature range.

4.2. Corresponding Requirements from RAS

Table 1 Requirements from RAS to be satisfied by the test

Requirement Number (from RAS)	Requirement Description
DR 2.1.1	Internal allowable BIRDS-4 temperature range shall be -15 to +50 deg Celsius.
DR 2.1.2	External allowable BIRDS-4 temperature range shall be from -20 to +55 deg Celsius.
DR 3.1.1	Temperature of the battery shall be monitored.
DR 3.1.2	Internal boards shall provide temperature data.
DR 3.1.3	Reaction wheel shall not overrun to limit its temperature.

5. Test Description

5.1. Test Place and Time

5.1.1. Test Date

The Thermal Vacuum Test will be conducted by the next schedule:

From:		
YY	MM	DD

To:		
YY	MM	DD

Total of day(s).

This schedule includes setup preparation, the actual test cycles (with satellite functional test) and setup recovery.

5.1.2. Test Place

Center for Nanosatellite Testing, Laboratory of Spacecraft Environment Interaction Engineering, Kyushu Institute of technology, 1-1 Sensui, Tobata, Kitakyushu, 804-8550 Fukuoka, Japan.

5.2. Test Contents

The test shall consist of:

a) Preparation of the satellite, thermocouples (TCs), connectors, GS setup and other materials to be used for the test.
b) Attachment of TCs to the satellite and checking the response.
c) Satellite assembly and checking of satellite functionality in normal laboratory setup (in BIRDS Room condition).
d) Installation of the satellite, TCs, and connectors inside the vacuum chamber and checking connectivity and responses.
e) Checking the satellite functionality inside the vacuum chamber before closing (atmospheric condition).
f) Vacuuming.
g) Measurement of temperature of various satellite points in vacuum condition during the thermal vacuum test (especially at extreme cold condition, extreme hot condition and during the temperature transition).
h) Checking the satellite functionality during the thermal vacuum test (especially at extreme cold condition, extreme hot condition and during the temperature transition).
i) Checking battery heater operation during the thermal vacuum test.
j) Setup recovery and removing the satellite from the vacuum chamber.

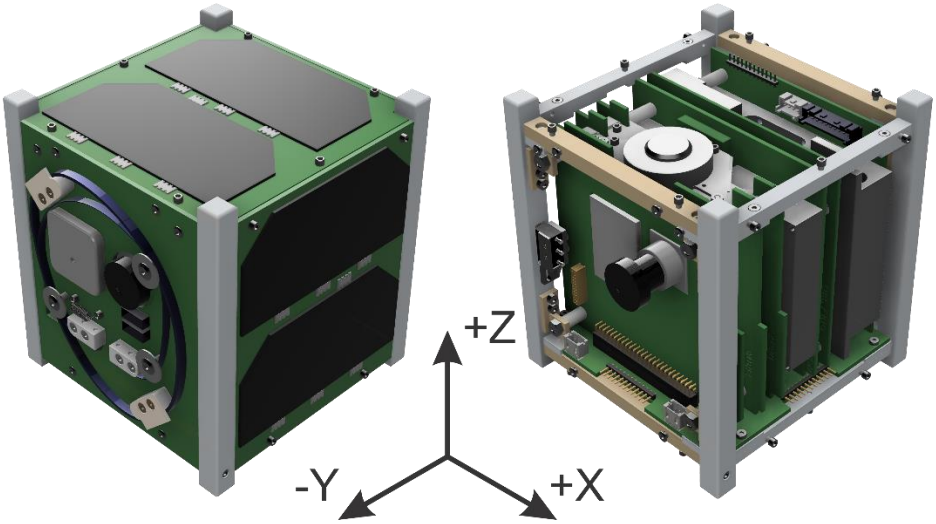
5.3. Test Article

The test article description is shown in Table 2

Table 2 Test article description

No.	Article name	Quantity	Manufacturer
1	BIRDS-4 FM	3	-

The EM 3D model is shown in Figure 1



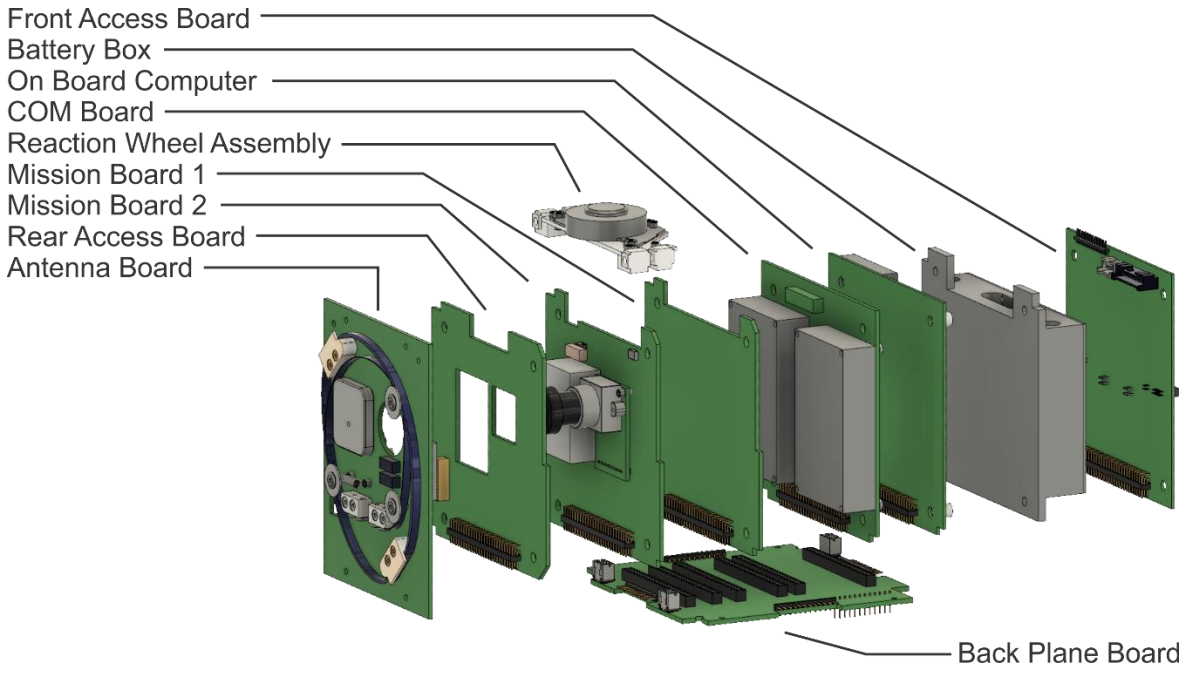


Figure 1 BIRDS-4 FM 3D model

5.4. Test Flow, Level and Conditions

The chamber pressure should be kept below $1 * 10^{-4}$ $[Pa]$ during all conditions of the thermal vacuum test. In this pressure range, heat exchange by molecular flow is negligible. Table 3 summarizes originally planned and reached temperature range and number of cycles of the test. After experimenting with the first cycle, a target of -15ºC and +50 °C are taken as control temperatures for internal boards.

Table 3 Temperature range for internal boards and number of cycles

	Originally Planned	Reached
Worst cold	$-15\ °C$	
Worst hot	$+30\ °C$	
Number of cycles	4	

6. Test Facility, Setup and Equipment

6.1. Test Facility

Specifications of the thermal vacuum chamber are given in Table 4.

Table 4 Vacuum chamber specification

No.	Items	Specification
1	Name	Thermal vacuum test equipment (Space Chamber)
2	Size	L1700 x L1500 mm (shroud inner diameter)
3	Material	Stainless steel
4	Ultimate Vacuum	$5.0 * 10^{-6}\ [Pa]$
5	Shroud Temperature	$-185°C$
6	Size of test table	W500 x D500 x H500 mm. 50kg
7	Characteristics	Satellite rail + gauge Clean booth Power output: 400W x6 Heat input current introduction terminal 32 Signal terminal: BNC x3 SMA x2 Thermocouple: Type K x80 Relay AC x3 DC x3

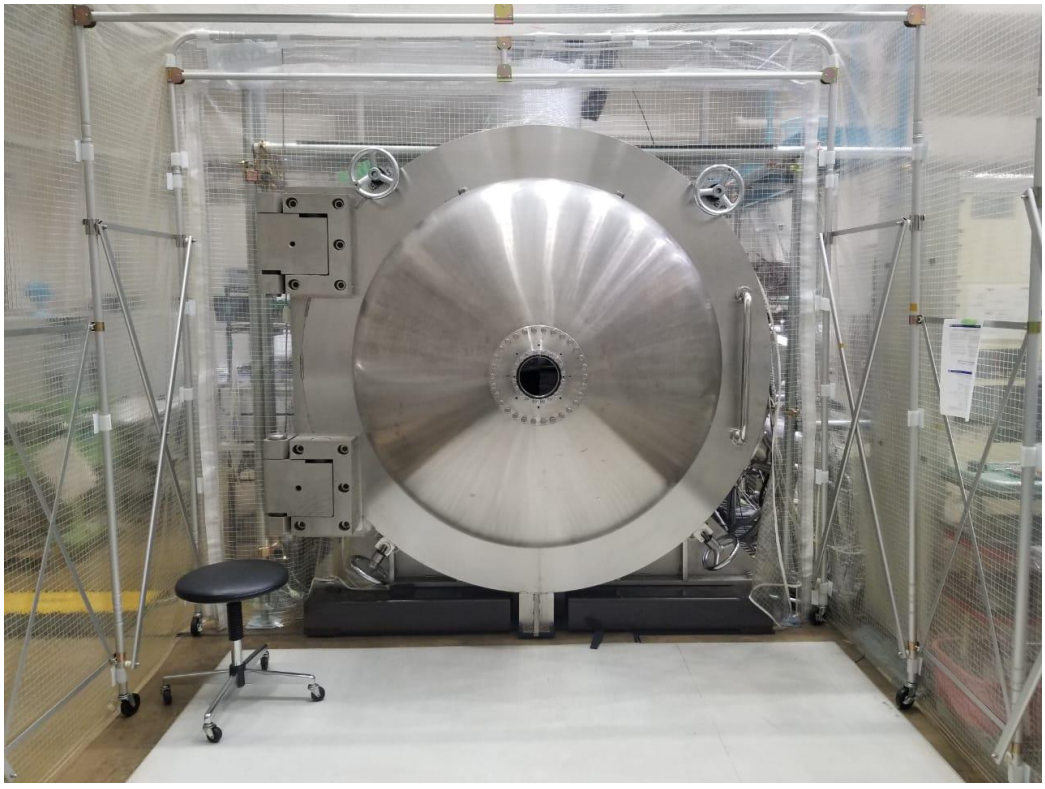


Figure 2 Space Chamber at CeNT

6.2. Test Setup

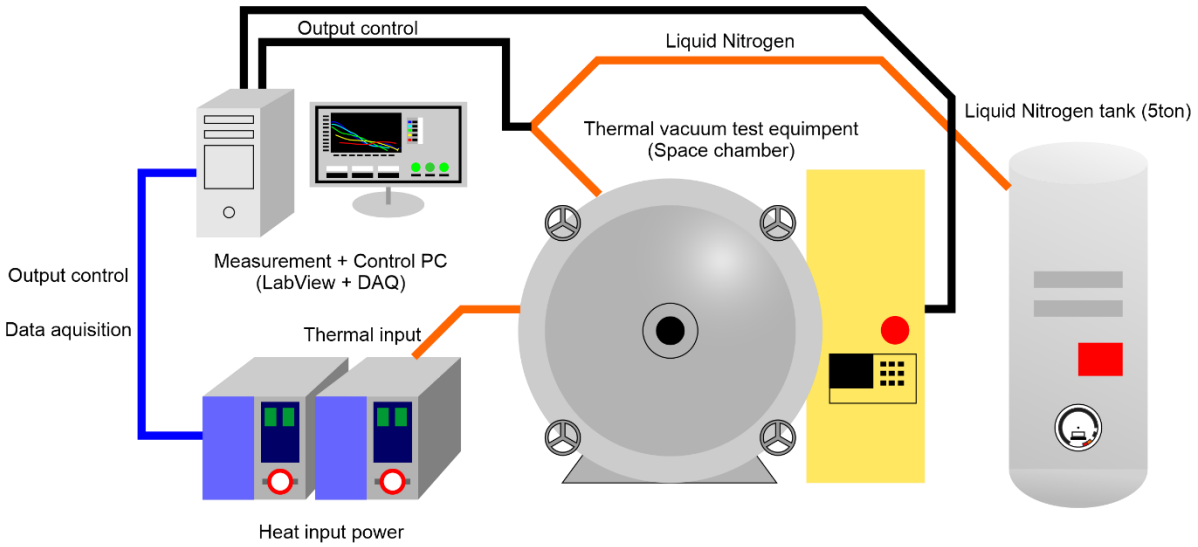


Figure 3 Overall test setup

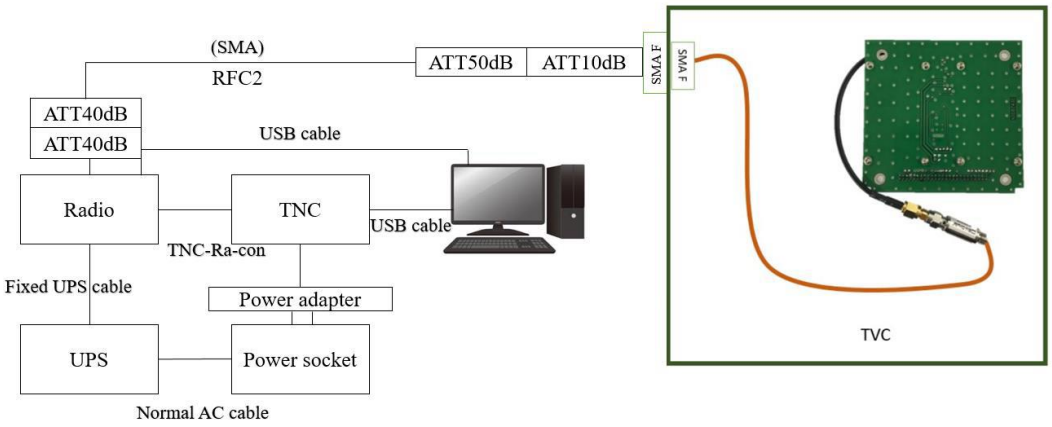


Figure 4 Connection from COM-UHF transceiver boards to GS equipment

6.3. Thermal Cycle Profile

- The test is planned to be conducted for 4 cycles (4 cold and 4 hot) as shown in Figure 5.
- At the extreme cold temperature and at the extreme hot temperature of each cycle, soaking time would be two hours with one hour for functional testing. However, this was not the case while testing. The soak lasted at least half an hour with about another half an hour for functional testing.
- There were total 10 temperature measurement points for the satellite, including the six on the external panel points.
- The monitoring/control temperature was average of six external panels.
- The worst hot condition for the external panel was +55°C.
- The battery heater of the satellite thermal subsystem would be activated at 8°C and less.
- The battery temperature was controlled to go close to 0°C. However, in real case, the battery temperature went below 0°C during functional testing.

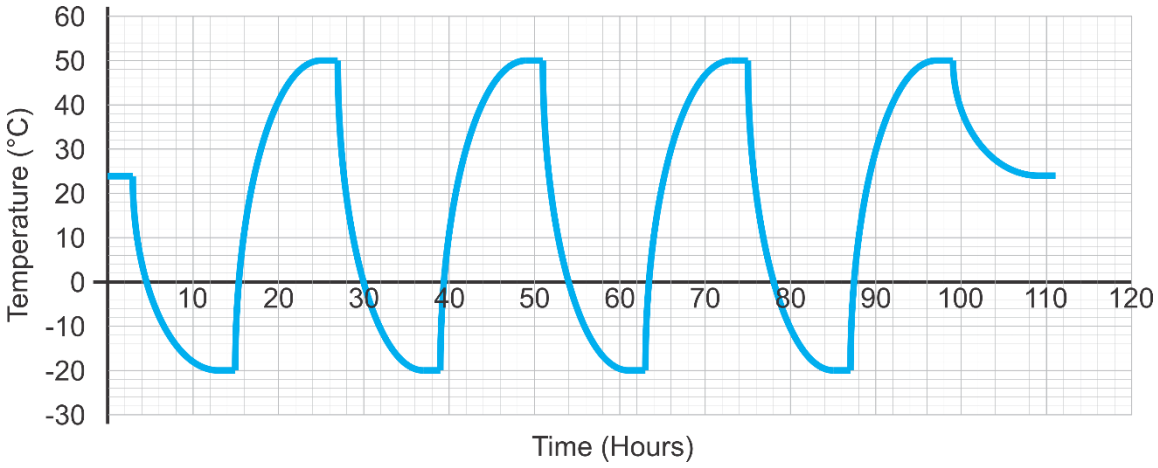


Figure 5 Planned Thermal cycle profile.

6.4. Heater positions

The next table provides the sheet heater parameters such as position, size, resistance and maximum power that can be used for the test.

Heater Number	Position	Size	Resistance	Total Resistance	Power supply number

Figure 6 Inside chamber configuration schematic

6.5. Thermocouple positions

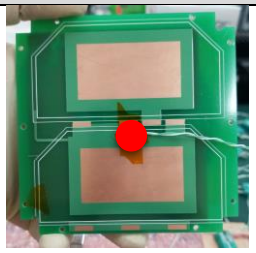
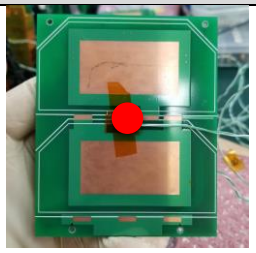
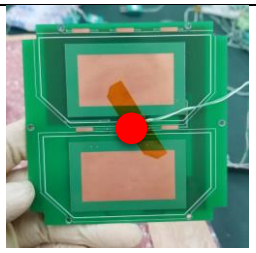
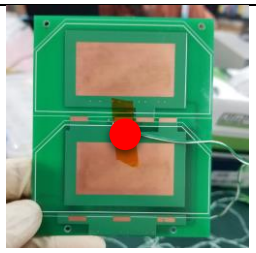
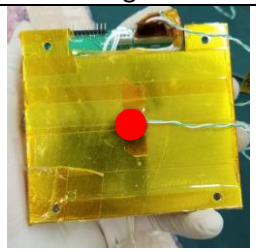
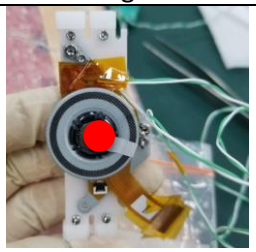
The thermocouple positions are summarized in the following table.

Table 5 Positions of Thermocouples

TC No.	Position	TC name in PC	Measurement point
1	PY_Battery Box (outside)	Bat_Box	Refer to Table 6
	PY_Reaction Wheel Assembly	Reaction_Wheel	
	PY_Positive X External Panel	Pos_X_Panel	
	PY_Negative X External Panel	Neg_X_Panel	
	PY_Positive Y External Panel	Pos_Y_Panel	
	PY_Negative Y External Panel	Neg_Y_Panel	
	PY_Positive Z External Panel	Pos_Z_Panel	
	PY_Negative Z External Panel	Neg_Z_Panel	
	PH_Battery Box (outside)	Bat_Box	
	PH_Reaction Wheel Assembly	Reaction_Wheel	
	PH_Positive X External Panel	Pos_X_Panel	
	PH_Negative X External Panel	Neg_X_Panel	
	PH_Positive Y External Panel	Pos_Y_Panel	

	PH_Negative Y External Panel	Neg_Y_Panel	
	PH_Positive Z External Panel	Pos_Z_Panel	
	PH_Negative Z External Panel	Neg_Z_Panel	
	JP_Battery Box (outside)	Bat_Box	
	JP_Reaction Wheel Assembly	Reaction_Wheel	
	JP_Positive X External Panel	Pos_X_Panel	
	JP_Negative X External Panel	Neg_X_Panel	
	JP_Positive Y External Panel	Pos_Y_Panel	
	JP_Negative Y External Panel	Neg_Y_Panel	
	JP_Positive Z External Panel	Pos_Z_Panel	
	JP_Negative Z External Panel	Neg_Z_Panel	
	Cylinder Shroud		
	Front wall		
	Back wall		
	Heater1		
	Heater2		
	Heater3		
	Heater4		
	Heater5		
	Heater6		

Table 6 Measurement Points

External Panels		
 Positive Z External Panel	 Positive Y External Panel	 Positive X External Panel
 Negative Z External Panel	 Negative Y External Panel	 Negative X External Panel
Internal Components		
Y axis Magnetic Coil	Z axis Magnetic Coil	
 Battery Box	 Reaction Wheel Assembly	

6.6. Attachment of Thermocouples

The next figure shows the steps of attaching the thermocouples to satellite surfaces and components.

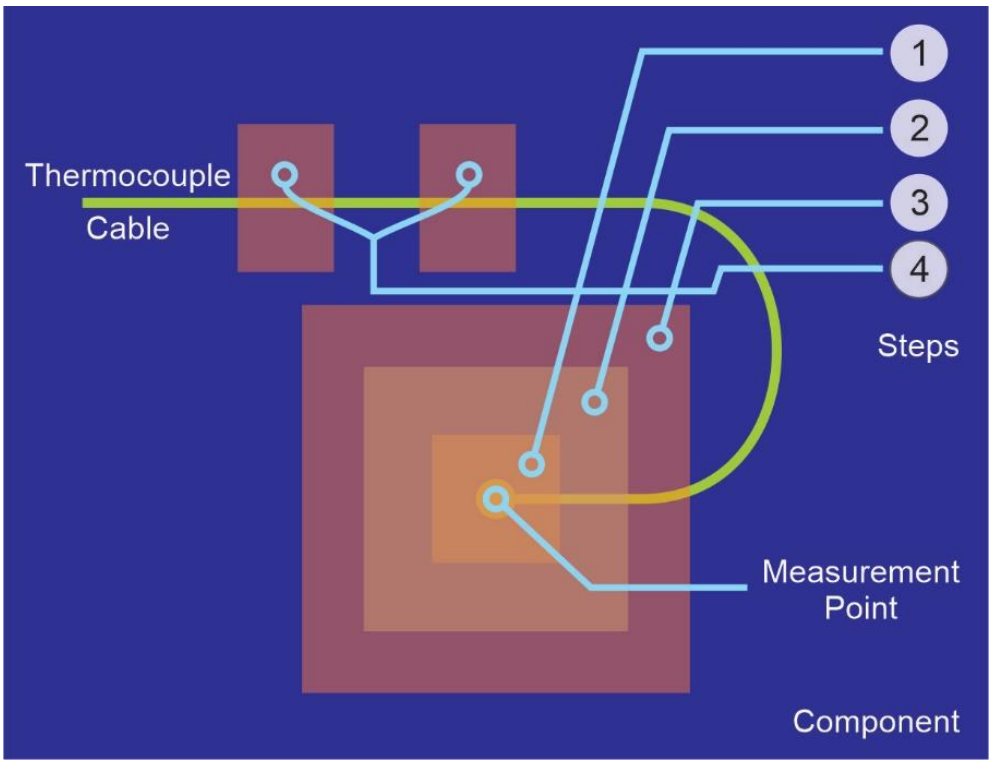


Figure 7 Thermocouple attachment

- Step 1: Cover thermocouple tips by a small piece of polyimide tape.
- Step 2: Fix the thermocouple terminal using aluminum tape.
- Step 3: Cover the aluminum tape by polyimide tape.
- Step 4: Fix the thermocouple wire by polyimide tapes.

6.7. Placement of satellite inside the chamber

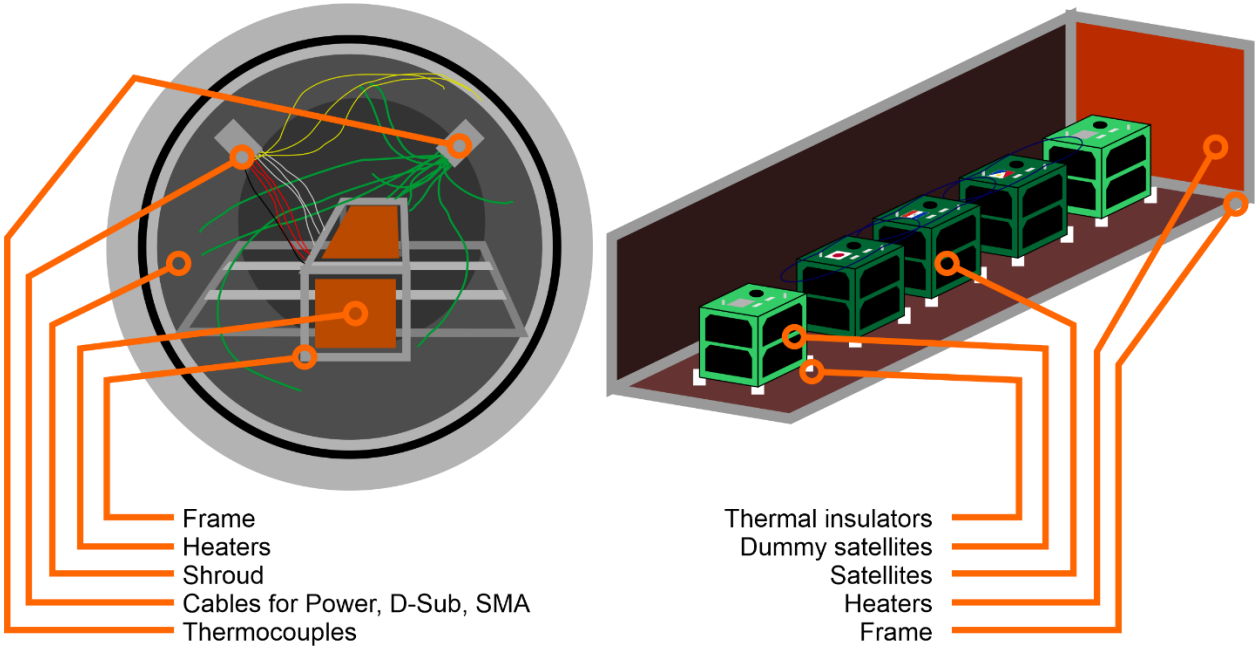


Figure 8 Placement of Satellite inside the chamber

6.8. Equipment and Measuring Instruments

Table 7 Equipment and measuring instruments details

No	Equipment	Quantity	Model	Comments
1	Thermocouple	20	Type-K	-180 to +1300 °C
2	Data Acquisition PC	1	N/A	For chamber control
3	DAQ-mx	2	NI 9213	24-bit ADC
4	Power Supplies	2		0-320V
5	Transceiver	1	IC-9100	For functional test
6	Attenuator	3		For functional test
7	Functional Test PC	2	N/A	For functional test
8	Terminal Node Controller	1	KPC-9612+	For functional test
9	Sheet heaters			

7. Test Schedule

The test schedule is shown in Table 8 below, the schedule is tentative and can be changed base on the actual test conditions.

Table 8 Test schedule

PROCEDURE	MM DD	MM DD	MM DD	MM DD	MM DD	MM DD	MM DD	MM DD	MM DD
	AM	PM	AM	PM	AM	PM	AM	PM	AM
Preparation of the satellite, thermocouples (TCs), sheet heaters, connectors, GS setup and other materials to be used for the test									
Attachment of TCs to the satellite and checking the response									
Satellite assembly and checking of satellite functionality in normal laboratory setup (in Room condition) Installation of the satellite, TCs, and connectors inside the vacuum chamber and checking connectivity and responses									
Checking the satellite functionality inside the vacuum chamber before closing (atmospheric condition)									
Vacuuming									
Inject LN2									
Thermal Cycle									
De-vacuuming, setup recovery and removing the satellite from the vacuum chamber									

8. Detailed Test Procedure

Te detail test procedures shown in Table 9 with tasks need to be done before, during and after the test, the person in charge of each task should check the task once it is finished.

Verification		
Preparation and checking the satellite and chamber		
(Cold Cycle)	Make vacuum and conduct the thermal test and functional test	(Hot Cycle)
Stop the test, clean up and check the satellite		

Table 9 Detailed test procedure

No	Procedure	Check	Date	Time	Responsible	Comments
1	Verify all satellite functionalities and operation (preliminary, in BIRDS Room)		0000/00/00	00:00		
2	Prepare and check thermocouples					
3	Check chamber's thermocouple connections					
4	Check chamber's D-Sub and RF port connections					
5	Disassemble structure and center box					
6	Attach thermocouples to Satellite					
7	Take photos and note the TCs' positions					
8	Reassemble satellite and check thermocouples and heaters connection					
9	Check satellite functionalities					
10	Move satellite to the chamber					
11	Install the satellite in the chamber					
12	Check again all heaters' and TCs' response on the PC					
13	Check satellite functionalities					
14	Chamber closing, start of rough vacuum					
15	Finish rough vacuum					
16	Start high vacuum					
17	High vacuum reached					
18	Start Functional test					
19	Finish Functional test					
20	Inject LN2					
21	Start cold ramp #1C					
22	Temp stabilization reached (cold) #1C					

23	Start Functional test #1C					
24	Finish Functional test #1C					
25	Start hot ramp #1C					
26	Temp stabilization reached (hot) #1C					
27	Start Functional test #1C					
28	Finish Functional test #1C					
29	Start cold ramp #2C					
30	Temp stabilization reached (cold) #2C					
31	Start Functional test #2C					
32	Finish Functional test #2C					
33	Start hot ramp #2C					
34	Temp stabilization reached (hot) #2C					
35	Start Functional test #2C					
36	Finish Functional test #2C					
37	Start cold ramp #3C					
38	Temp stabilization reached (cold) #3C					
39	Start Functional test #3C					
40	Finish Functional test #3C					
41	Start hot ramp #3C					
42	Temp stabilization reached (hot) #3C					
43	Start Functional test #3C					
44	Finish Functional test #3C					
45	Start cold ramp #4C					
46	Temp stabilization reached (cold) #4C					
47	Start Functional test #4C					
48	Finish Functional test #4C					
49	Start hot ramp #4C					
50	Temp stabilization reached (hot) #4C					
51	Start Functional test #4C					
52	Finish Functional test #4C					
53	Stop LN2 injection					

54	Get to room temperature					Turn on chamber heater to increase chamber temperature
55	Room temperature reached					
56	Start Functional test					
57	Finish functional test					
58	De-vacuuming and recovery					
59	Do fit check with satellite					
60	Remove TCs					

9. Test Output

9.1. Data analysis strategy

Table 10 below show the operating temperature range for the satellite. The temperature of each component during the test should be inside of operating temperature range.

Table 10 Components operating temperature range

Component	Operating Temperature Range (°C)		Recorded Temperature Range during Test (°C)	
	Lowest	Highest	Lowest	Highest
Battery Box Assembly	0	+40		
Front Access Board	-40	+80		
On Board Computer	-40	+85		
Communication Board	-20	+60		
Mission Board 1	-40	+85		
Mission Board 2	-20	+70		
Rear Access Board	-40	+80		
Back Plane Board	-40	+105		
X axis MTQ				
Y axis MTQ				
Z axis MTQ				
Reaction Wheel				
Plus X Panel	-40	+85		
Minus X Panel	-40	+85		
Plus Y Panel	-40	+85		
Minus Y Panel	-40	+85		
Plus Z Panel	-40	+85		
Minus Z Panel	-40	+85		

9.2. Test report

Temperature profile of all measurement points during the test.

Results on functionality tests.

Evaluation of the test results.

9.2.1. Battery heater operation

Results on battery heater operation.

9.2.2. Antenna deployment

Results on antenna deployment test.

10. Quality Insurance

Temperature [oC]: 20 ± 5

Humidity [%]: 70 ± 10

Atmosphere: 10^-5 Pa

11. Personnel Assignment

Table 11 show the personnel assignment for the thermal vacuum test.

Table 11 Personnel Assignment During Setup Preparation

Task	Responsible Person
Ground Station Equipment	
Preparation and installation of heaters and thermocouples	
D-sub Connector Preparation	
Battery Charging Setup	
Antenna preparation and deployment test trial	
Documentation	
Support	
TVT lead	
Team management	

12. Safety Requirement

During the test period, in consideration of the safety of work, strictly observe the following matters:

1. During testing, the field officer shall supervise all work and instruct properly to assure the safety of work.
2. Use a crane or a handcart to move any heavy item with anticipated risk.
3. The ceiling crane shall be operated only by licensed personnel. I-bolt / lifting equipment should be inspected each time before operating the crane. No entry to the area under the suspended material is permitted.
4. During testing, keep unnecessary items away from the testing machine.
5. Gloves shall be worn when handling a satellite or sensors.
6. Do not place any item on safety-related motion lines, such as the emergency exit, corridor, fire extinguishers, etc.
7. When a high voltage apparatus is used, turn off the power before inspecting, touching, or modifying, etc.
8. In the case of a natural disaster or a serious accident, take emergency measures and prevent secondary accidents immediately. Then communicate via the following emergency communication links shown below in Figure 9.

Figure 9 Emergency procedure flow chart

12.1. What to say in Japanese

a) You are the center, 4th floor

Kyushu kogyo daigaku, kogakubu no sogo kenkyu ichi-goto, yonkai de _____nin fushosha (= injured)/kasai (= fire) ga hassei shimasita. Watashi ha _____ (your name) desu.

Kyushu Institute of Technology, General Research Building No. 1, 4th floor. There are _____ people injured/There is a fire. I am _____ (your name).

b) You are at SVBL, 1st floor

Kyushu kogyo daigaku, kogakubu no sogo kenkyu ni-goto, ichikai de _____nin fushosha (= injured)/kasai (= fire) ga hassei shimasita. Watashi ha _____ (your name) desu.

Kyushu Institute of Technology, General Research Building No. 2, 1st floor. There are _____ people injured/There is a fire. I am _____ (your name).

c) You are at SVBL, 2nd floor

Kyushu kogyo daigaku, kogakubu no sogo kenkyu ni-goto, nikai de _____nin fushosha (= injured)/kasai (= fire) ga hassei shimasita. Watashi ha _____ (your name) desu.

Kyushu Institute of Technology, General Research Building No. 2, 2nd floor. There are _____ people injured/There is a fire. I am _____ (your name).

d) You are at SVBL, 3rd floor

Kyushu kogyo daigaku, kogakubu no sogo kenkyu ni-goto, sankai de _____nin fushosha (= injured)/kasai (= fire) ga hassei shimasita. Watashi ha _____ (your name) desu.

Kyushu Institute of Technology, General Research Building No. 2, 3rd floor. There are _____ people injured/There is a fire. I am _____ (your name).