BIRDS-3 Project

EM Vibration Test Report

Kyushu Institute of Technology
Laboratory of Spacecraft Environment Interaction Engineering

Date	Version Number	Writer	Annotations
2018/8/18	V1.0	Makiko	First Draft
2018/8/24	V1.1	Makiko, Abhas	Edit all
2018/8/24	V1.2/V1.3	Makiko, Abhas	Added torque marks, battery board damaged image
2018/8/25	V1.4	Makiko	Edit points which Masui-sensei pointed out
2018/8/25	V1.5	Abhas	Discussion, Conclusion

Contents

List of Acronyms and Abbreviations

A	
AMP	Charge Amplifier
AT	Acceptance Test
ATV	Automatic Transfer Vehicle
B	
BAT	Battery
C	
CH	Channel
CAM	Camera
C.P.	Control Point
D	
DAQ	Data Acquisition System
DR	Design Requirements
Dir	Direction
E	
EM	Engineering Model
F	
FFT	Fast Fourier Transform
FM	Flight Model
G	
Go-p	G zero to peak
Grms	G Root mean square
H	
HTV	HII Transfer Vehicle
J	
JEM	Japanese Experimental Module
P	
PC	Personal Computer
Q	
QT	Qualification Test
R	
RAS	Requirement Allocation Sheet
S	
STM	Structure and Thermal model
STR	Structure team
SVBL	Satellite Venture Business Laboratory
SpX	Space X

1. Introduction

Vibration test demonstrates the ability of a test article to withstand the vibrations environment imposed.

The aim of the test is to demonstrate that the test article can withstand mechanical vibration when excited with acceleration levels induced by launch vehicles including HTV, SpX and Orbital Cygnus.

2. Referenced Documentation

Document number	Document description	Revision level or Release date
JX-ESPC-101133-B	JEM Payload Accommodation Handbook; Small Satellite Deployment Interface Control Document	Vol 8. January, 2015
Torque Chart	Maryland Metrics Torque Chart	Retrieved May, 2016 https://mdmetric.com/tech/torqcht1a.pdf

3. Test Purpose

3.1. Overall Test Description

The purpose of this test is to evaluate the impact of vibration by launch vehicle on BIRDS-3 CubeSat structure.

3.2. Success Criteria

The success of the vibration test will be determined based on the following criteria;

(1) Shift in Natural Frequency: A significant shift in natural frequency indicates *workmanship failure* (loose components on/in the structure). Any broken parts in the primary structure shall be judged as a *failure in design*.

(2) Torque Mark Shift: When observed visually, there should be no shift in torque marks on the screws on the test article after each test. Any shift in torque mark shows a *workmanship failure* in setting the required torque before testing

(3) Fracture Critical Parts:
   i. All external fasteners and fasteners holding the main structure shall not be loose after vibration
   ii. Glass components (including solar cells and camera lens) shall not be broken after vibration

(4) Deployable Components
The deployable UHF monopole antenna shall not deploy during vibration.

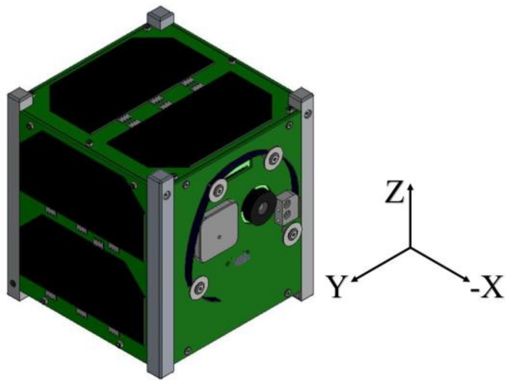
(5) Radio Interference
Satellite shall not broadcast radio (CW) during vibration. Radio is set to CW frequency throughout the test to confirm no broadcast is received from satellite.

(6) Satellite Function
Satellite functional test shall be conducted before and after vibration tests. Satellite should function the same after the vibration test as before the test. Refer to “BIRDS-3_Fit_Check_Report_A”

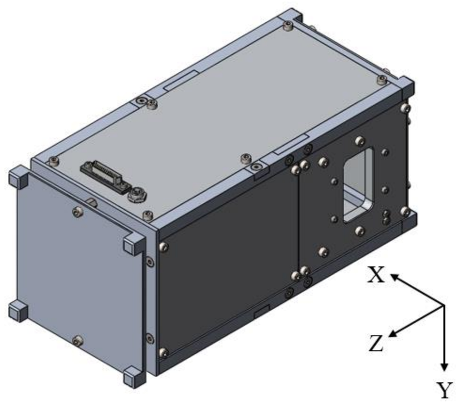
4. Test article(s)

Table 4-1 Test articles

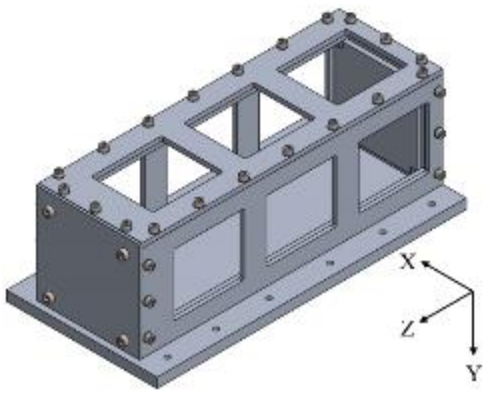
	Article name	Number	Manufacturer	Mass (kg)	Dimension (mm)
1	BIRDS-3 EM	1	HMP	1.110	100 (L) x 100 (W) x 113.5 (H)
2	Dummy CubeSat	2	Kyutech Factory	1.44	100 (L) x 100 (W) x 100 (H)
3	3U Pod	1		4.620	



1. BIRDS-3 EM



2. Dummy CubeSat (1U x 2)



3. 3U Pod

Figure 4-1 Test Articles

5. Test Facility Equipment

- Test center name and address

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

- Test facility

Table 5-1 Vibration testing system specification

No.	Items	Specification		
1	Type	F-35000BD/LA36AP(made by EMIC)		
2	Exciting Force	Sine		35.0 kN
		Random		28.0 kN
		Shock		87.5 kN
3	No-load maximum acceleration	Vertical	Sine	1060.0 m/s^2
			Shock	1470.0 m/s^2 (0-p)
		Horizontal	Sine	460.5 m/s^2
			Shock	1151.3 m/s^2 (0-p)
4	Maximum loading mass	Vertical		400 kg
		Horizontal		500 kg
5	Horizontal vibration table size	50cm×50 cm		
6	Power	49.0 kVA		

Figure 5-1 Vibration Test Machine

The Figure 5-1 is an image of the vibration test machine used for the vibration test.

6. Acceleration measurement point

The acceleration measurement points are shown in Figures 6-2 to 6-7 and Table 6-1.
CH1 to CH9 are acceleration measurement points for data acquisition.
C.P.1 and C.P.2 are acceleration measurement points for average value control for the vibration machine.

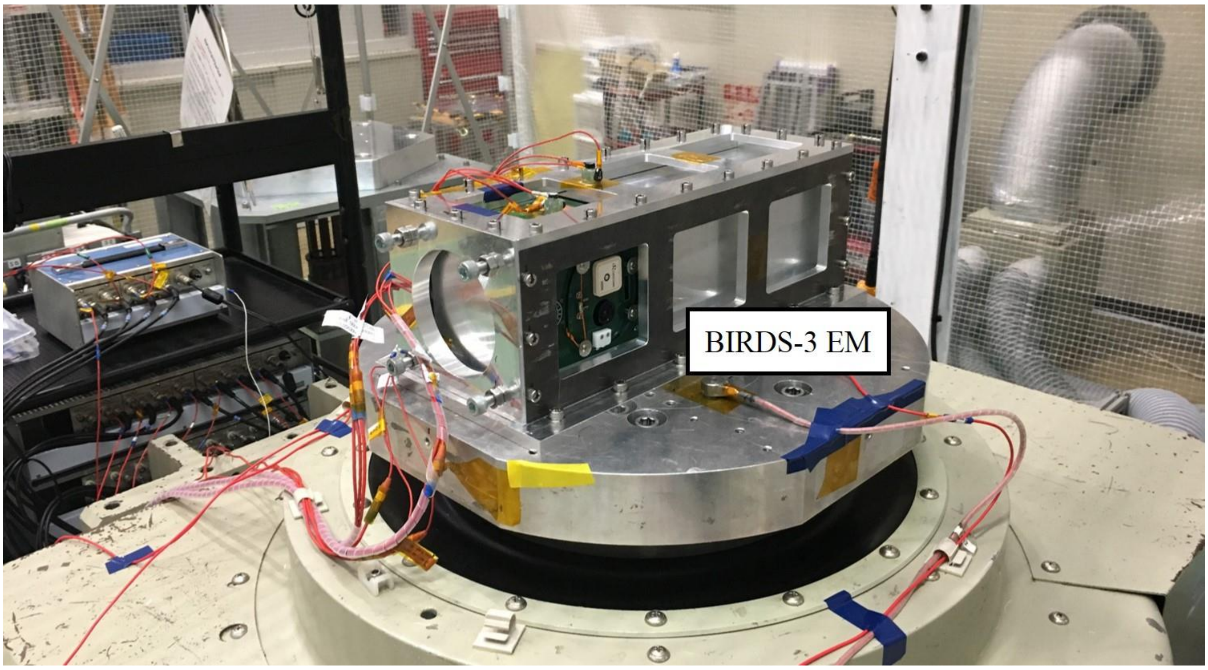


Figure 6-1 External view

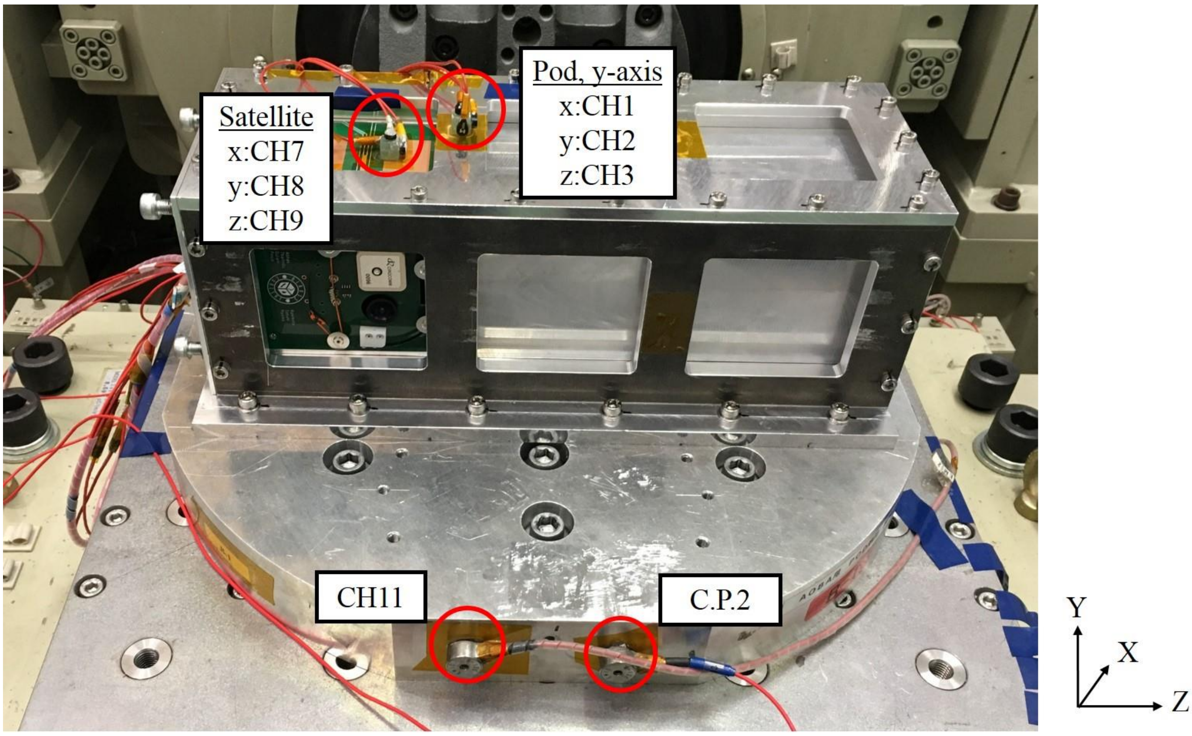


Figure 6-2 Measurement and control points of EM (X-axis vibration, -X side)

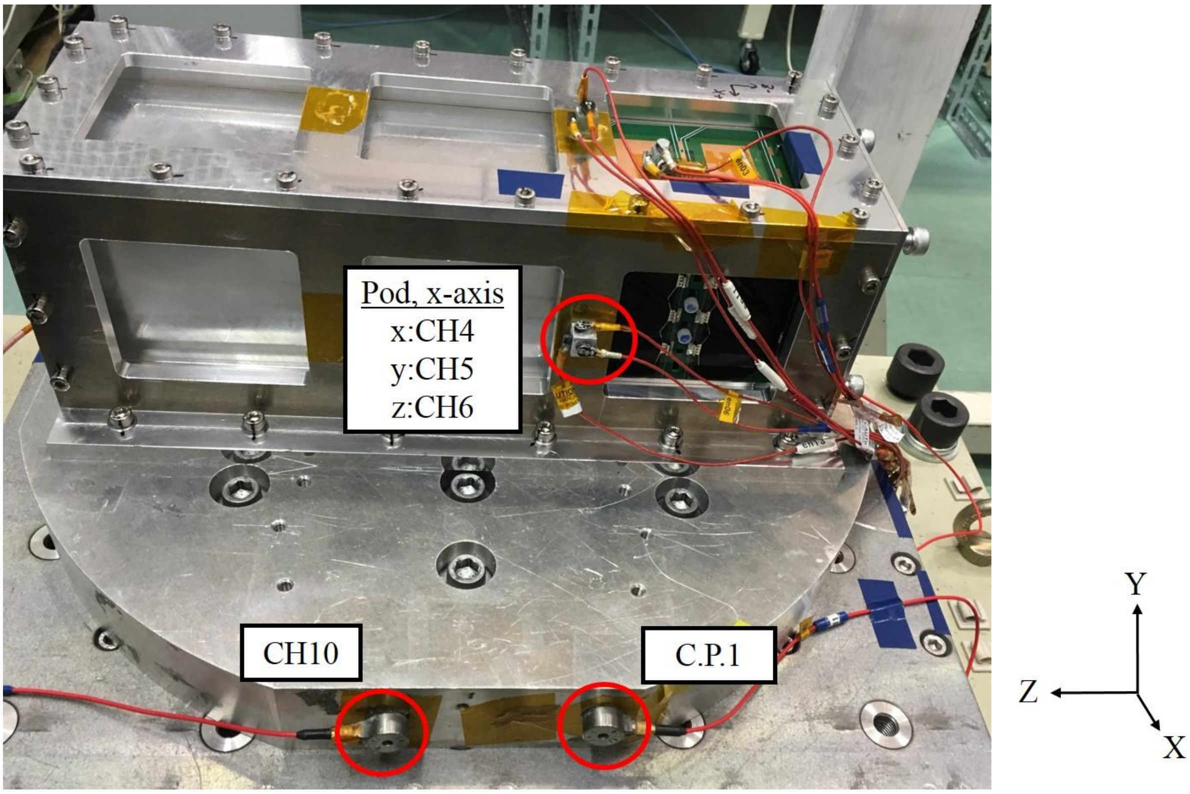


Figure 6-3 Measurement and control points of EM (X-axis vibration, X side)

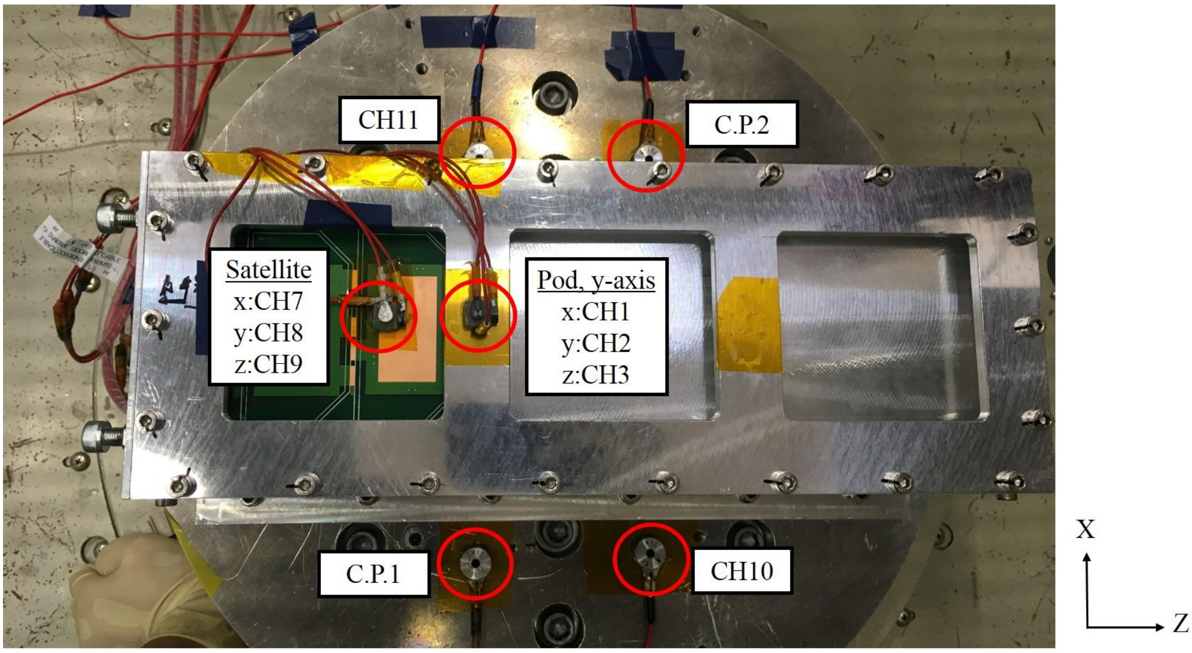


Figure 6-4 Measurement and control points of EM (Y-axis vibration, Top)

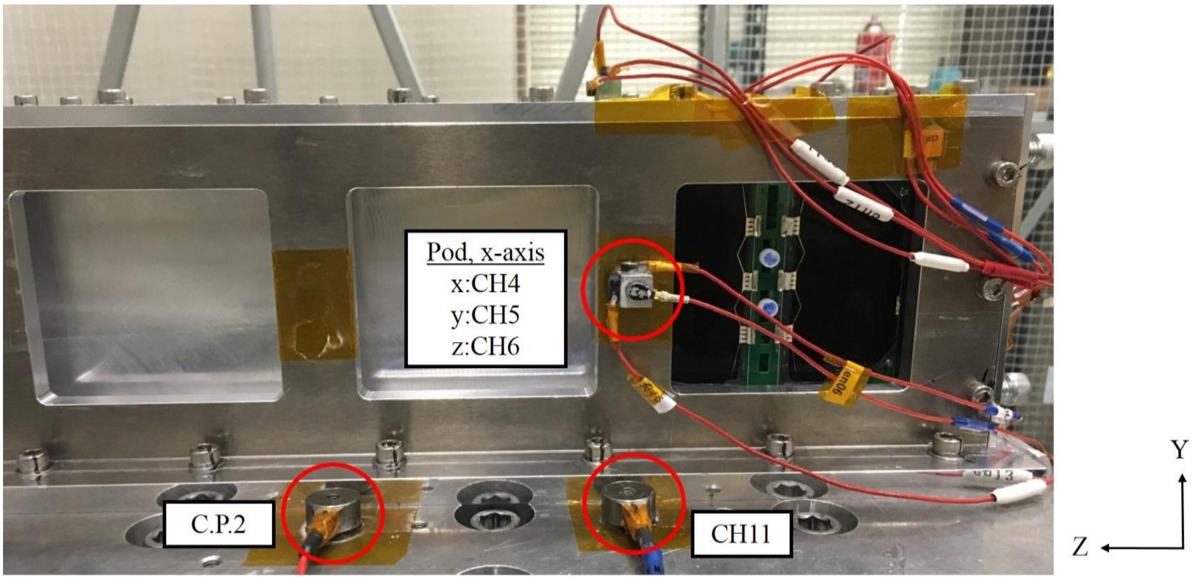


Figure 6-5 Measurement and control points of EM (Y-axis vibration, X side)

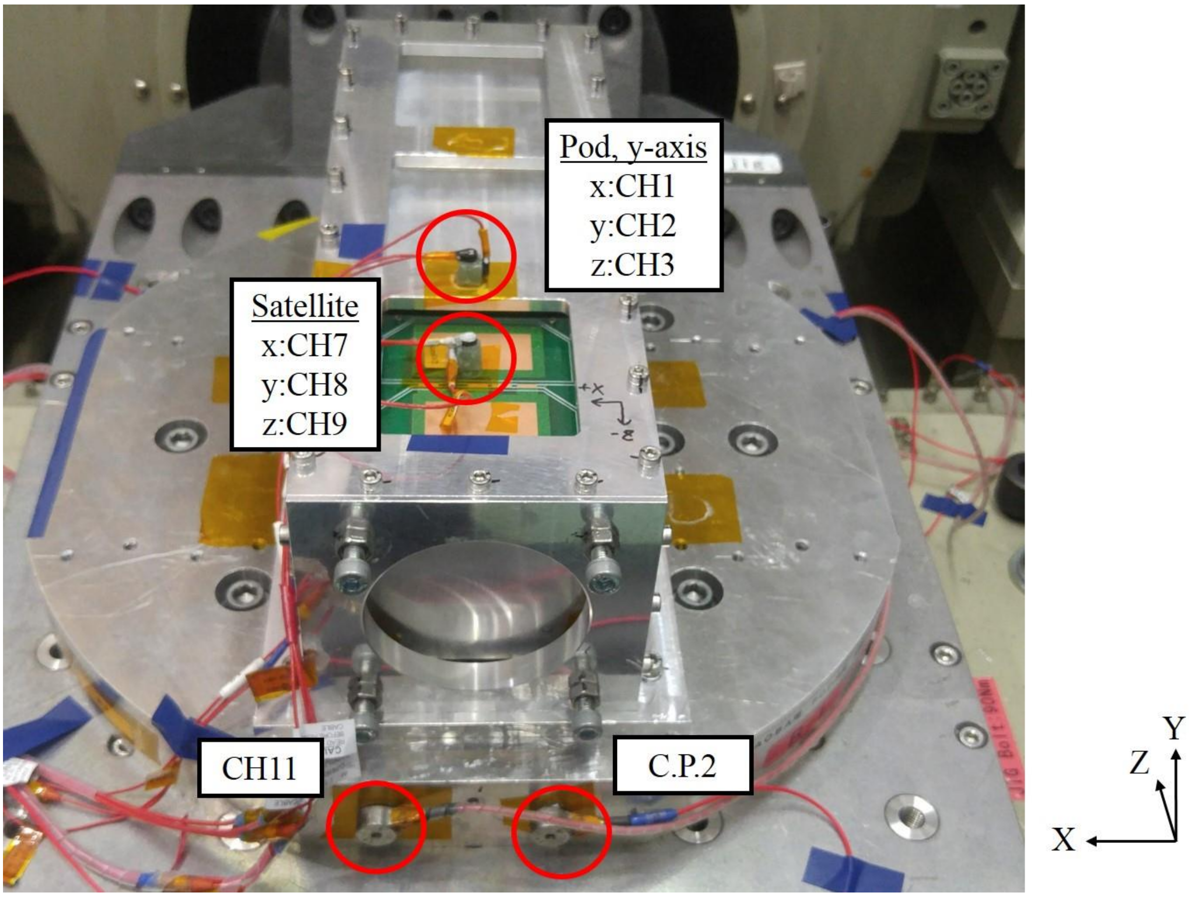


Figure 6-6 Measurement and control points of EM (Z-axis vibration, -Z side)

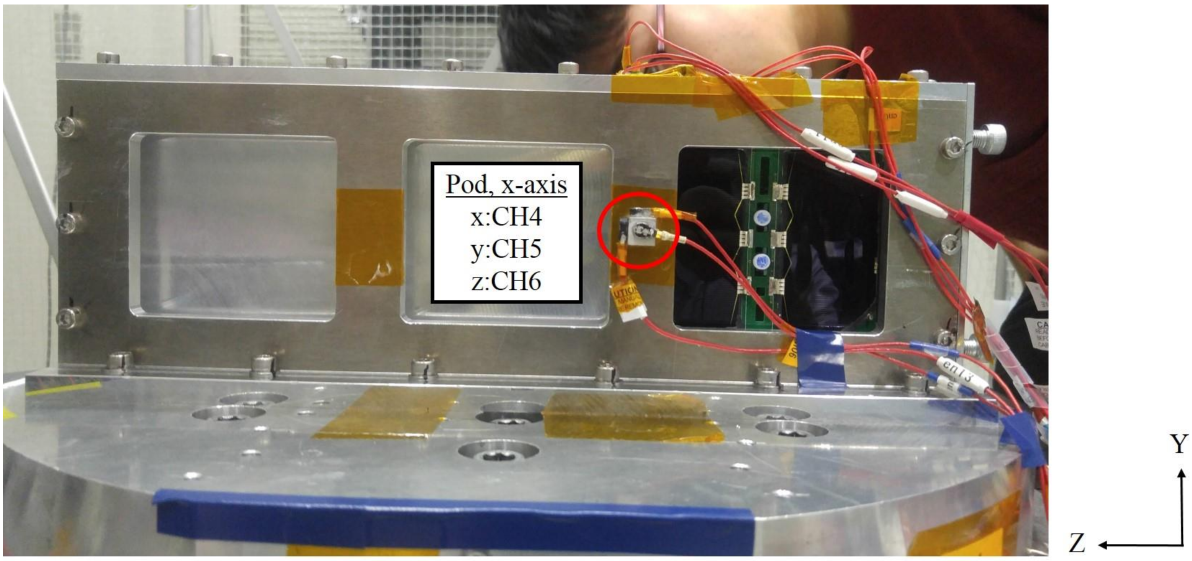


Figure 6-7 Measurement and control points of EM (Z-axis vibration, Side)

Table 6-1 Acceleration measurement point

CH	Axis	Mounting position	Channel/Accelerometer number
1	X	Pod, Y-axis	EN11
2	Y		EN12
3	Z		EN10
4	X	Pod, X-axis	EN05
5	Y		EN06
6	Z		EN13
7	X	Satellite, +Y panel	EN03
8	Y		EN01
9	Z		EN02
10	-	Jig	EM11
11	-	Jig	EM13
C.P. 1		Jig	EM12
C.P. 2		Jig	EM14

7. Test Description

7.1. Actual Test flow

01 Functional Test* → 02 Preparation →

Y axis: 03 Modal → 04 Random QT → 05 Modal → 06 Sine burst QT → 07 Modal

→ 08 Axis change →

Z axis: 09 Modal → 10 Random QT → 11 Modal → 12 Sine burst QT → 13 Modal

→ 14 Axis change →

X axis: 15 Modal → 16 Random QT → 17 Modal → 18 Sine burst QT → 19 Modal

→ 20 Clean up → 21 Functional Test*

Figure 7.1-1 BIRDS-3 EM vibration test flow

* These functional tests are performed independently of the vibration test.
Before modal survey, visual inspection was conducted.

7.2. Test set-up

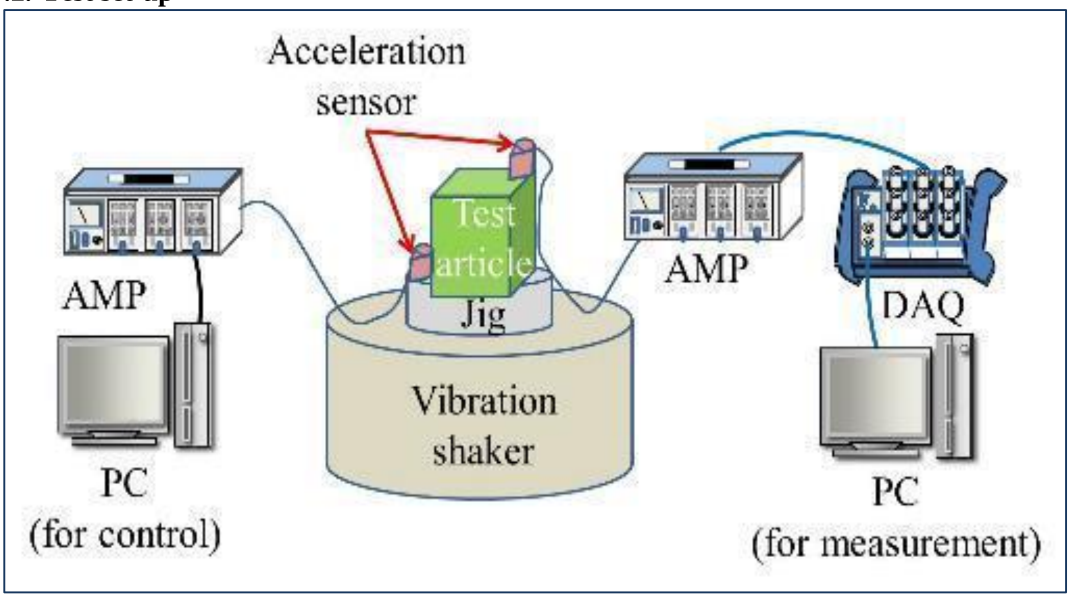


Figure 7.2-1 Schematic of Test Equipment

Table 7.2-1. Table shows the settings on the PC for control and measurement of data.

Vibration test type		**Modal survey**	**Sine burst**	**Random**
Vibration Profile		Random	Sine	Random
Vibration parameters	Test type	Modal	Sine Burst	Random
	Frequency band [Hz]: Min [Hz]	20	5	20
	Frequency band [Hz]: Max [Hz]	2000	100	2000
	Setting of measuring: Number of channels	12	12	12
	Setting of measuring: Measuring time [sec]	50	40	110
	Setting of measuring: Sampling rate [sample/sec]	10,000	5,000	10,000
	Setting of analysis: Number of FFT point	16,384	2048	16,384
	Setting of analysis: G/V	10	10	10
	Monitor (OSC) Display time (Sec)	0.2	0.2	0.2
	Monitor (OSC) Max value of voltage (V)	0.5	7	4
Vibration Machine control	Switch: Sine - Random	Random	Sine/Shock	Random
	External level	Half	Max	Max

7.3. Supporting analysis

The analysis of the vibration response of the test article shall be computed using LabVIEW program.

7.4. Test condition

The test shall consists of:

- Modal survey

Table 7.4-1 Modal survey test table

MODAL SURVEY			
Direction	**Frequency [Hz]**	**Acceleration [Grms]**	**Time [min]**
X, Y, Z	20~2000	0.5 (White Noise)	1

- Random vibration test
  The Random Acceleration Profile for the Test (Envelope) is as shown in Figure 7.4-2 derived from maximum PSD values of HTV, SpX and Orbital Cygnus launch vehicles as shown in Table 7.4-2

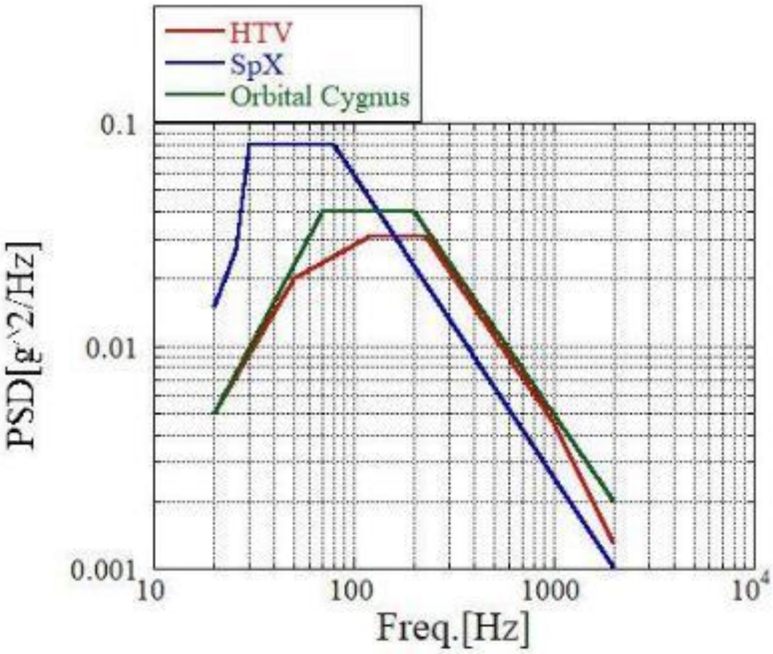


Figure 7.4-1 QT Random Vibration Profile for HTV, SpX and Orbital Cygnus
*Refer: Random Vibration and Acceleration, Table 2.4.1-1, Pg.17, JX-ESPC-101133B

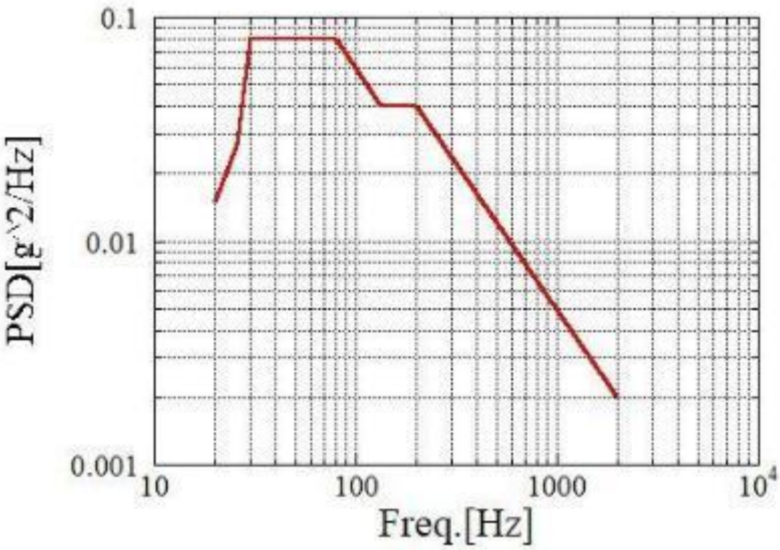


Figure 7.4-2 QT Test (Envelope) Random Vibration Profile

Table 7.4-2 Random Vibration of Each Launch Vehicle

HTV		**SpX DRAGON**		**Orbital Cygnus**	
Freq. (Hz)	PSD (g^2/Hz)	Freq. (Hz)	PSD (g^2/Hz)	Freq. (Hz)	PSD (g^2/Hz)
20	0.005	20	0.015	20	0.005
50	0.02	25.6	0.027	70	0.04
120	0.031	30	0.08	200	0.04
230	0.031	80	0.08	2000	0.002
1000	0.0045	2000	0.001		
2000	0.0013				
Overall (grms)	4.0	Overall (grms)	4.06	Overall (grms)	4.4
Duration(s)	60	Duration (s)	7.2	Duration (s)	60

Envelope	
Freq. (Hz)	PSD (g^2/Hz)
20	0.015
25.6	0.027
30	0.08
80	0.08
133	0.04
200	0.04
2000	0.002
Overall (grms)	
Duration (s)	60

*Refer: Random Vibration and Acceleration, Table 2.4.1-1, Pg.16, JX-ESPC-101133B

Table 7.4-3. Random QT table

RANDOM QT			
Direction	**Freq. [Hz]**	**QT**	
		Time [sec]	**Overall Grms value [Grms]**
Vertical axis (Y)	20~2000	120	6.8
Horizontal axis (X, Z)	20~2000		6.8 6.8

Table 7.4-4. Sine Burst QT table

SINE BURST QT			
Direction	**Freq. [Hz]**	**QT**	
		Number of waves	**Acceleration [G]**
Vertical axis (Y)	10~40	10 or more	22.6
Horizontal axis (X, Z)	10~40		22.6 22.6

*1 sec includes 10 waves or more. (Figure 10.1-3)

8. Test Schedule

Table 8-1 Test Schedule

Date	Time	Task
2018/08/16	9:00	Functional Test
	10:30	Preparation of Vibration test
	13:00	Y axis Vibration
	15:00	Z axis Vibration
	17:00	Change the vibration test machine axis
2018/08/17	9:00	X axis Vibration
	11:00	Clean up
	11:30	Functional Test

9. Test Result

(1) Shift in Natural Frequency: A significant shift in natural frequency indicates workmanship failure (loose components on/in the structure).

No major shift in frequency was observed. However,

Table 9-1 Test Result

Vibration	Satellite Axis	Result
X-axis	X-axis	No shift in frequency in Random and Sine Burst
	Y-axis	Amplitude of natural frequency of higher than X-axis
	Z-axis	No shift in frequency in Random and Sine Burst
Y-axis	X-axis	Slight shift in frequency in both Random and Sine Burst. Right shift corresponds to natural frequency increasing. This shows the test article was more compact than before
	Y-axis	Slight shift in frequency in Random test however, the graph shifted back to original frequency after Sine Burst
	Z-axis	No shift in frequency in Random and Sine Burst
Z-axis	X-axis	Slight shift in frequency in both Random and Sine Burst. Right shift corresponds to natural frequency increasing. This shows the test article was more compact than before
	Y-axis	Amplitude of natural frequency of higher than Z-axis
	Z-axis	No shift in frequency in Random and Sine Burst

During the start of X-axis vibration, torque was placed on the screws of Pod (Figure 9-1).

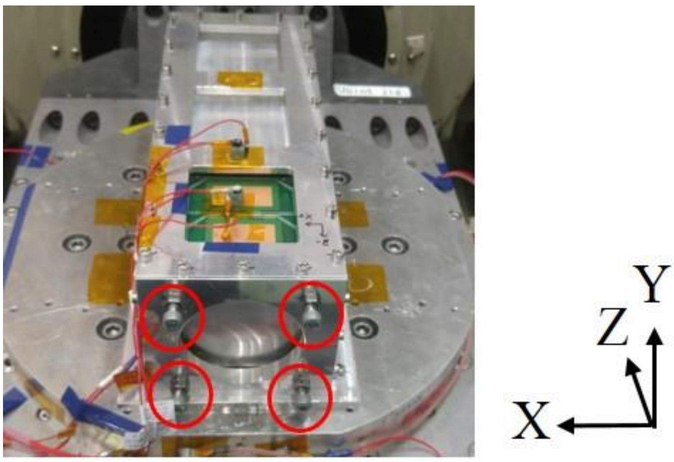
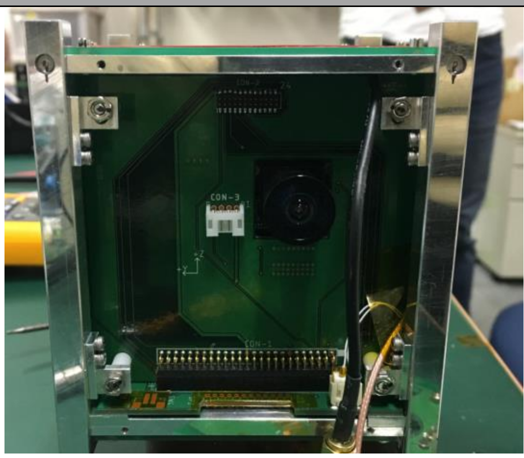
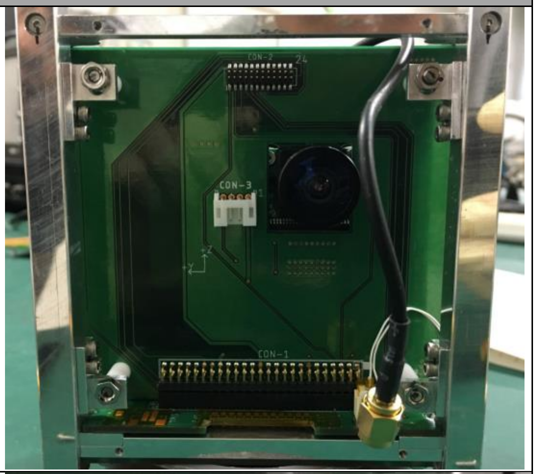
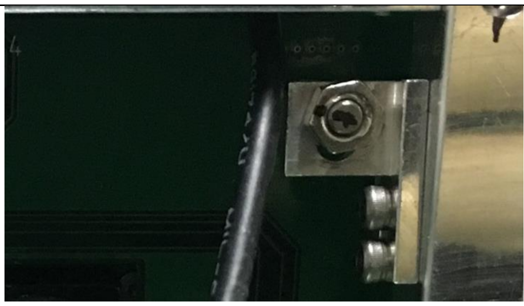
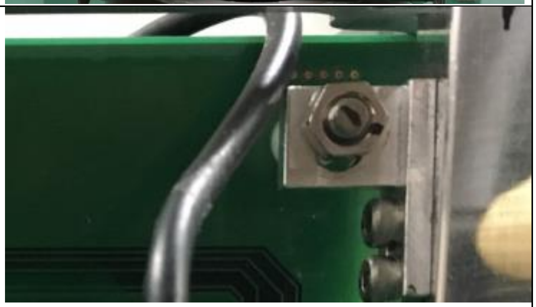


Figure 9-1 Pod screws position

(2) Torque Mark Shift: When observed visually, there should be no shift in torque marks on the screws on the test article after each test.

A few torque mark shift was observed. The nut that holds the spacers between the PCBs was observed to be have shifted. Table 9-2 shows the difference before and after.

Table 9-2 Nut torque mark displaced

Side	Before VT	After VT
-X		
Zoom Right Nut		

(3) Fracture Critical Parts:

i. All external fasteners and fasteners holding the main structure shall not be lose after vibration

ii. Glass components (including solar cells and camera lens) shall not be broken after vibration

Visual observation shows no breakage. The appearance before and after the test is shown in Table 9-4 for comparison. However, the DIP header of the Front Access Board (FAB) was in contact with the battery box during vibration board. This created small holes on the box. This is shown in Table 9-3.

Table 9-3 Damage seen on Battery Box

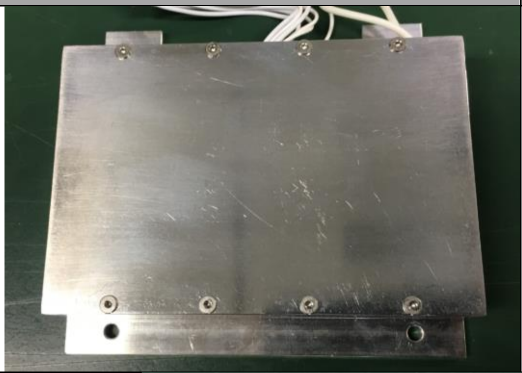
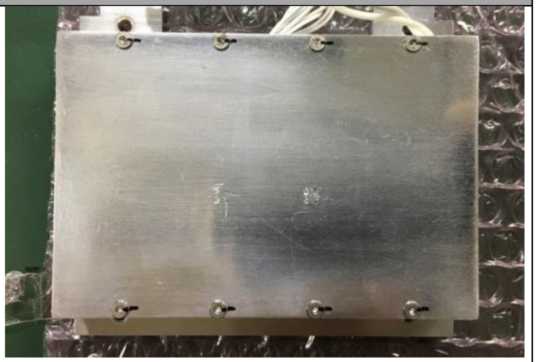
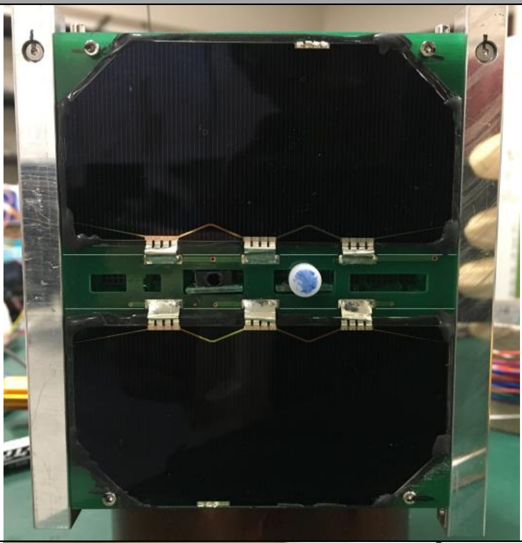
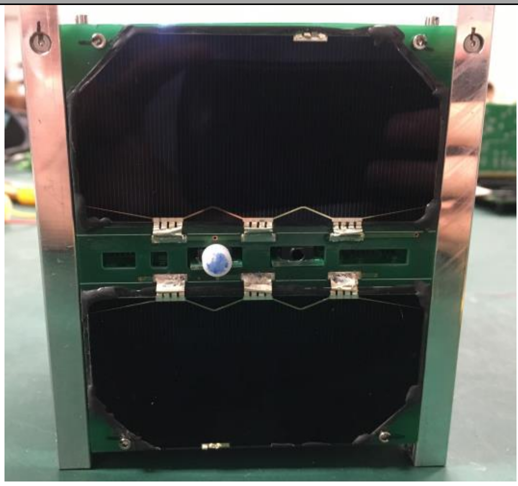
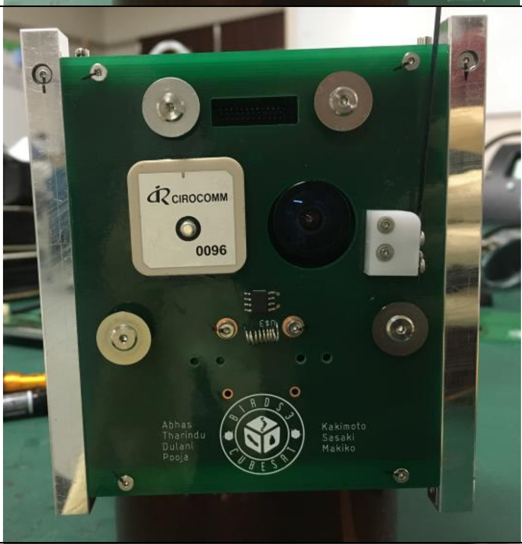
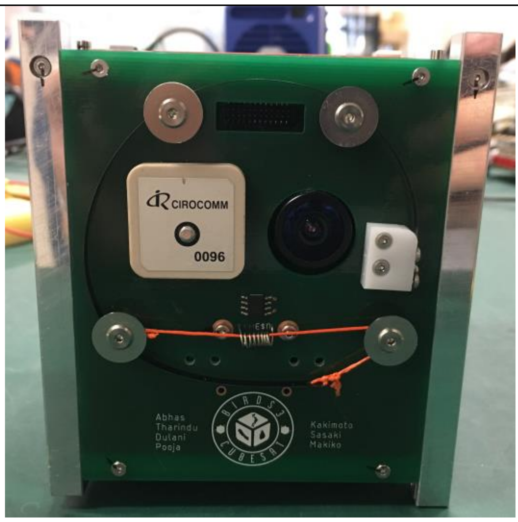
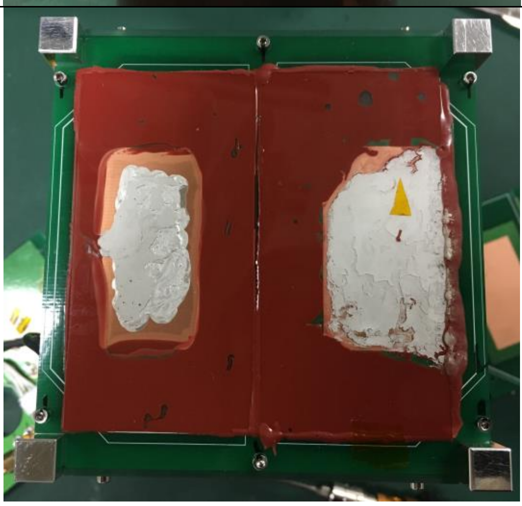
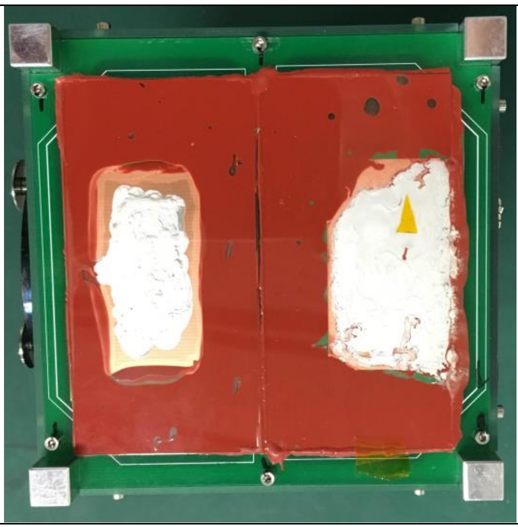
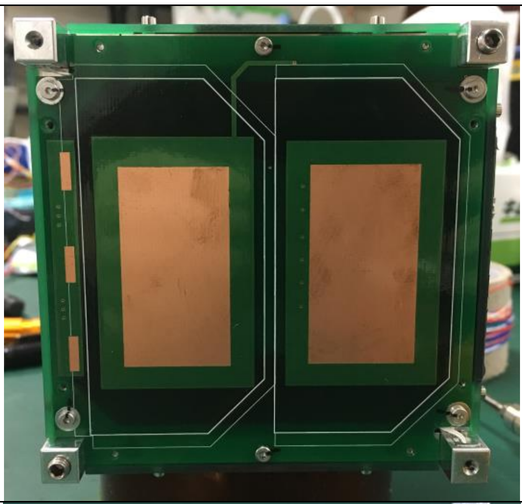
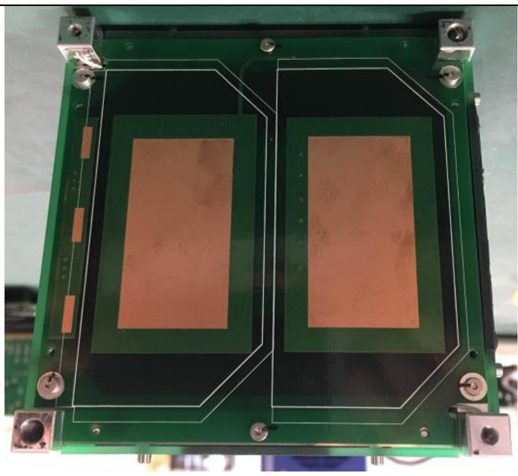
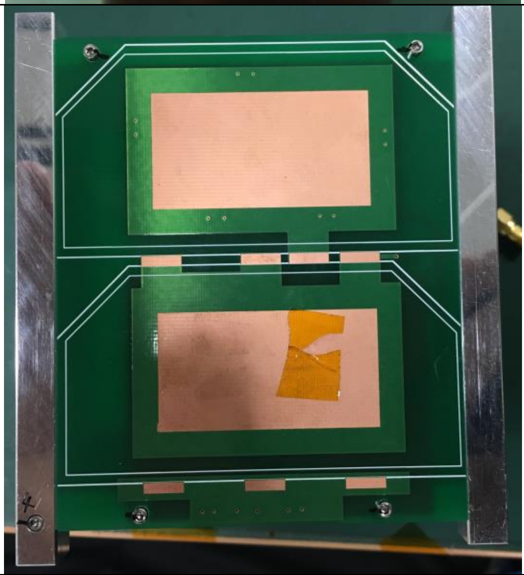
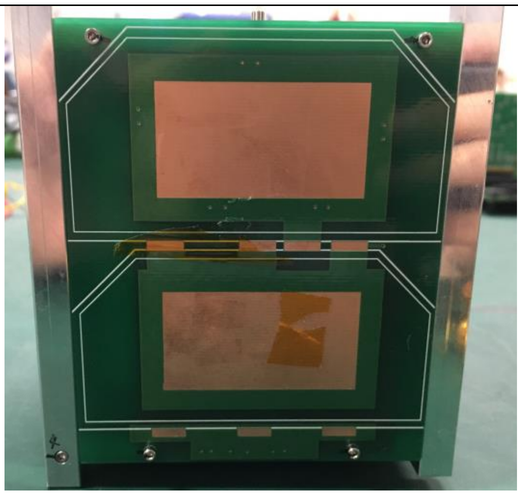
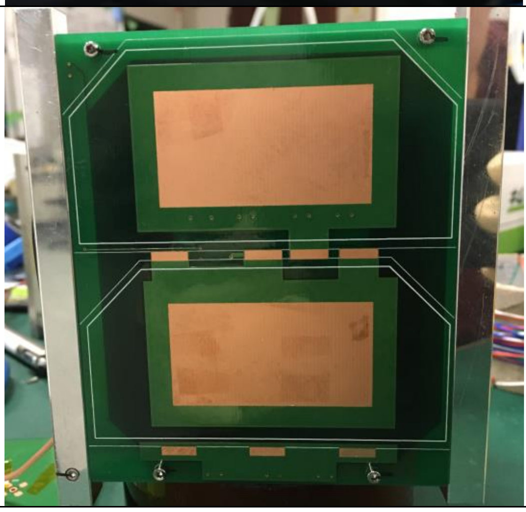
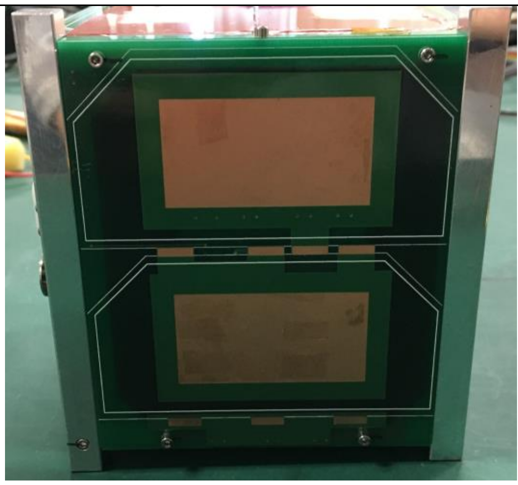
Part	Before VT	After VT
Battery Box		
-Y Panel		

Table 9-4 External structure before and after vibration test

BIRDS-3 EM

Panels	Before VT	After VT
+X		
-X		
+Z		

-Z		
+Y		
-Y		

(4) Deployable Components: The Deployable Antenna shall not deploy during vibration.

The Deployable Antenna did not deploy during vibration.

(5) Radio Interference: Satellite shall not broadcast radio (CW) during vibration. Radio is set to CW frequency throughout the test to confirm no broadcast is received from satellite.

Satellite did not broadcast radio (CW) during vibration.

(6) Satellite Function: Satellite functional test shall be conducted before and after vibration tests. Satellite function after vibration tests should be the same as before tests.

Satellite function after vibration tests was the same as before tests.

10. Acquired data

10.1 Figures 10.1-1 and 10.1-3 show control data (during X axis excitation).

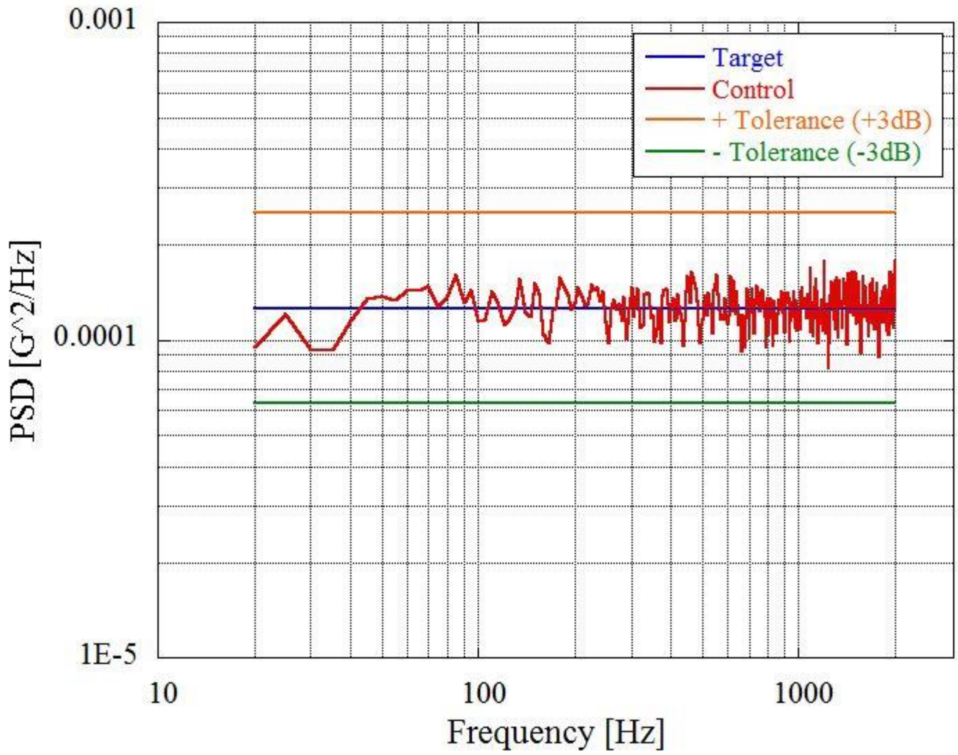


Figure 10.1-1 PSD pattern for Modal survey (X axis)

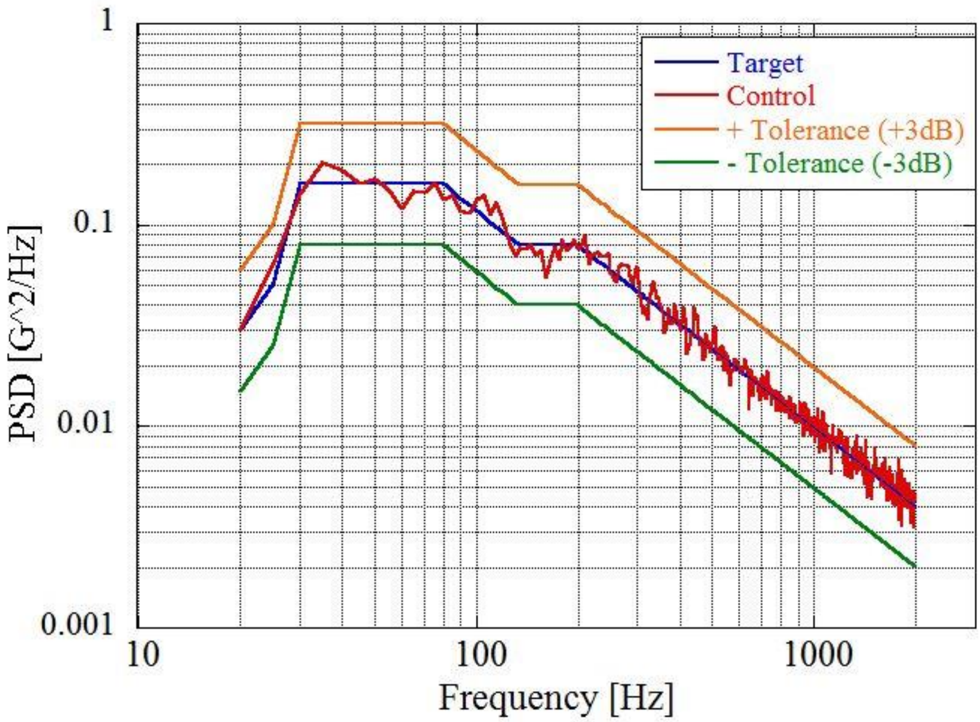


Figure 10.1-2 PSD pattern for Random QT (X axis)

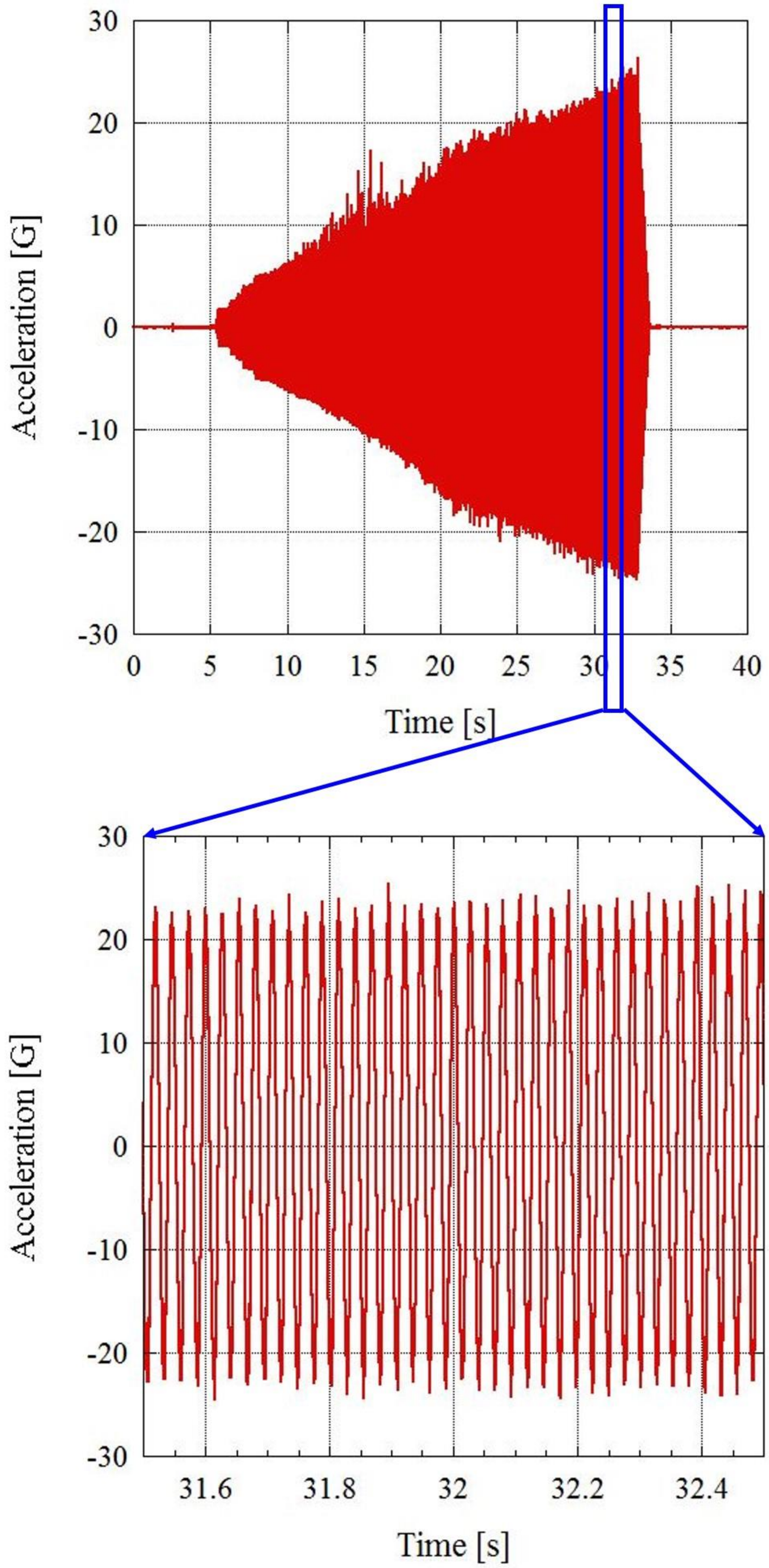


Figure 10.1-3 Sine burst QT waveform (X axis) (CH10)

10.2 Figures 10.2-1 to 10.2-4 show measurement data (during X axis excitation).

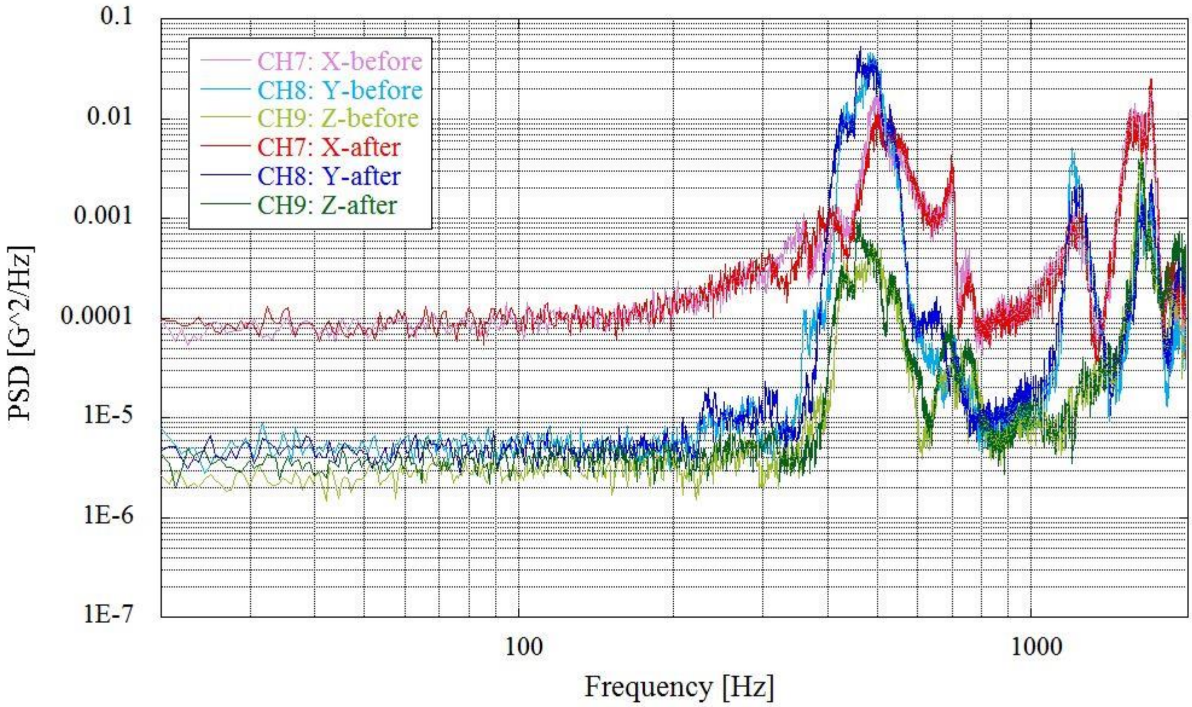


Figure 10.2-1 Modal survey for X axis (before and after Random QT, all axis)

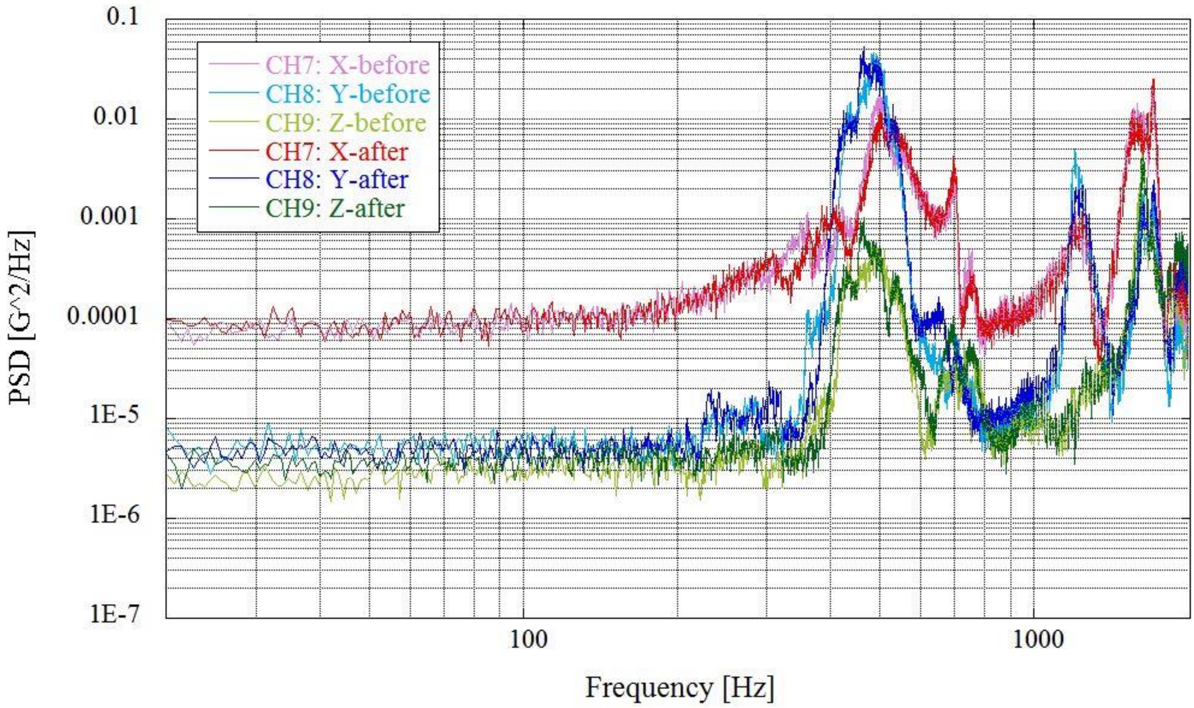


Figure 10.2-2 Modal survey for X axis (before and after Sine Burst QT, all axis)

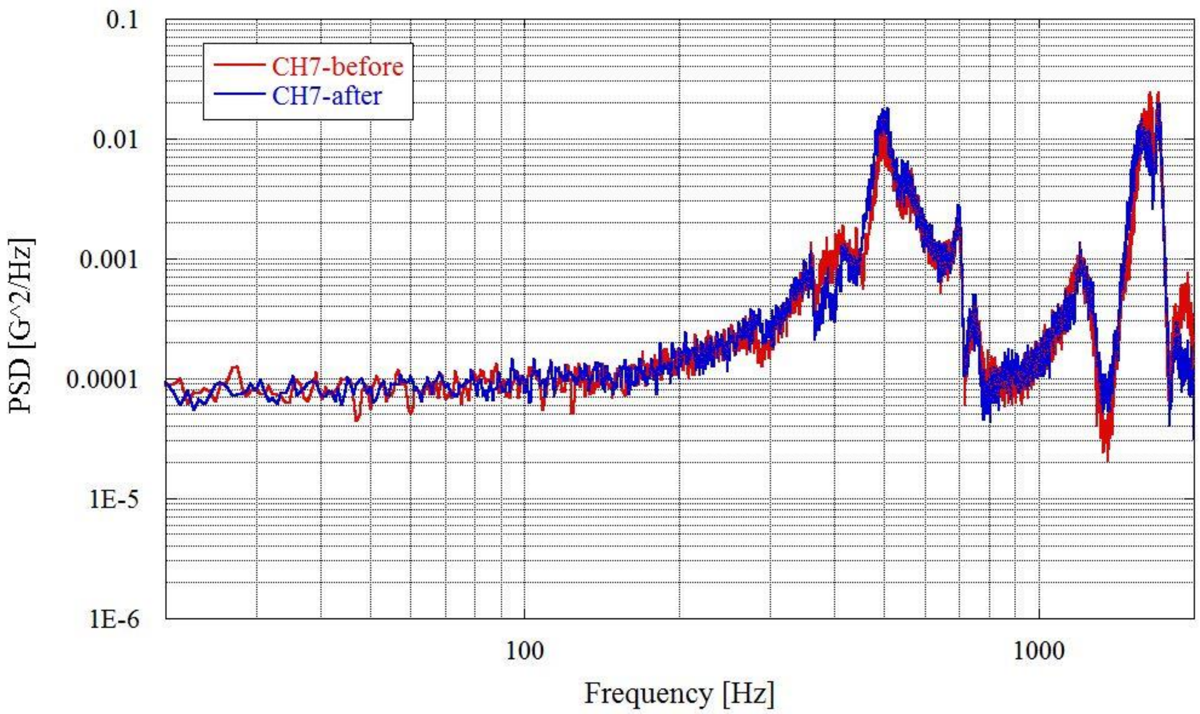


Figure 10.2-3 Modal survey for X axis (before and after Random QT, X axis)

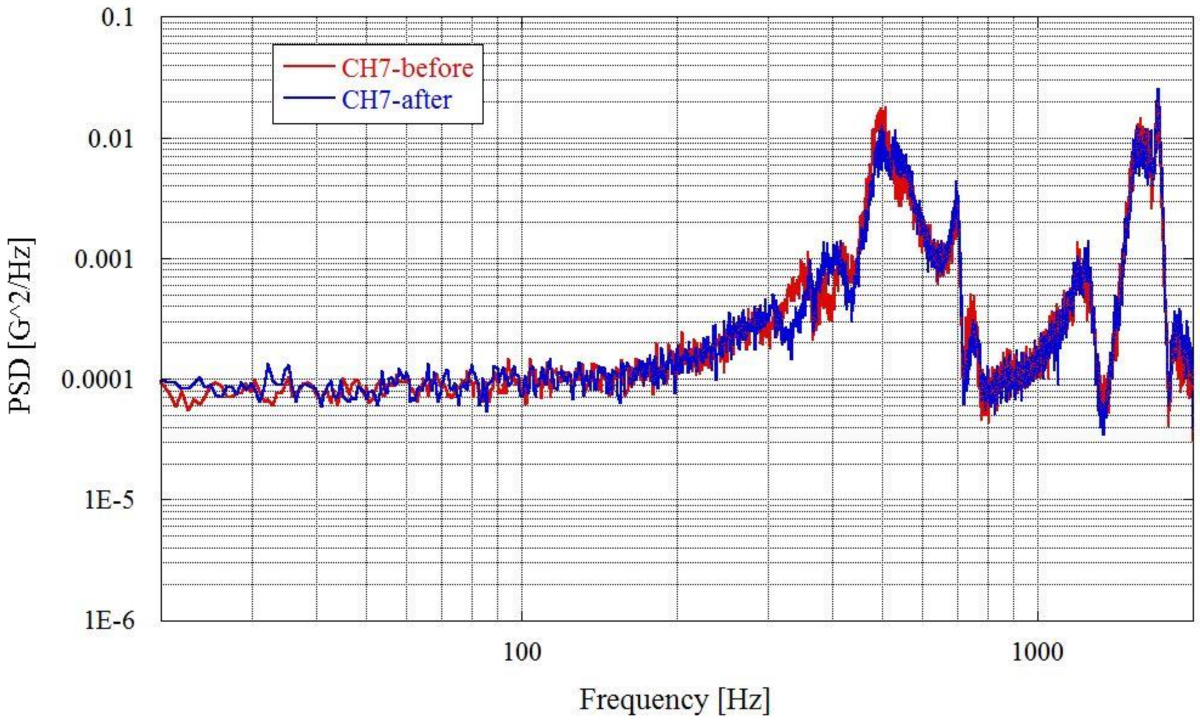


Figure 10.2-4 Modal survey for X axis (before and after Sine Burst QT, X axis)

10.3 Figures 10.3-1 to 10.3-4 show measurement data (during Y axis excitation).

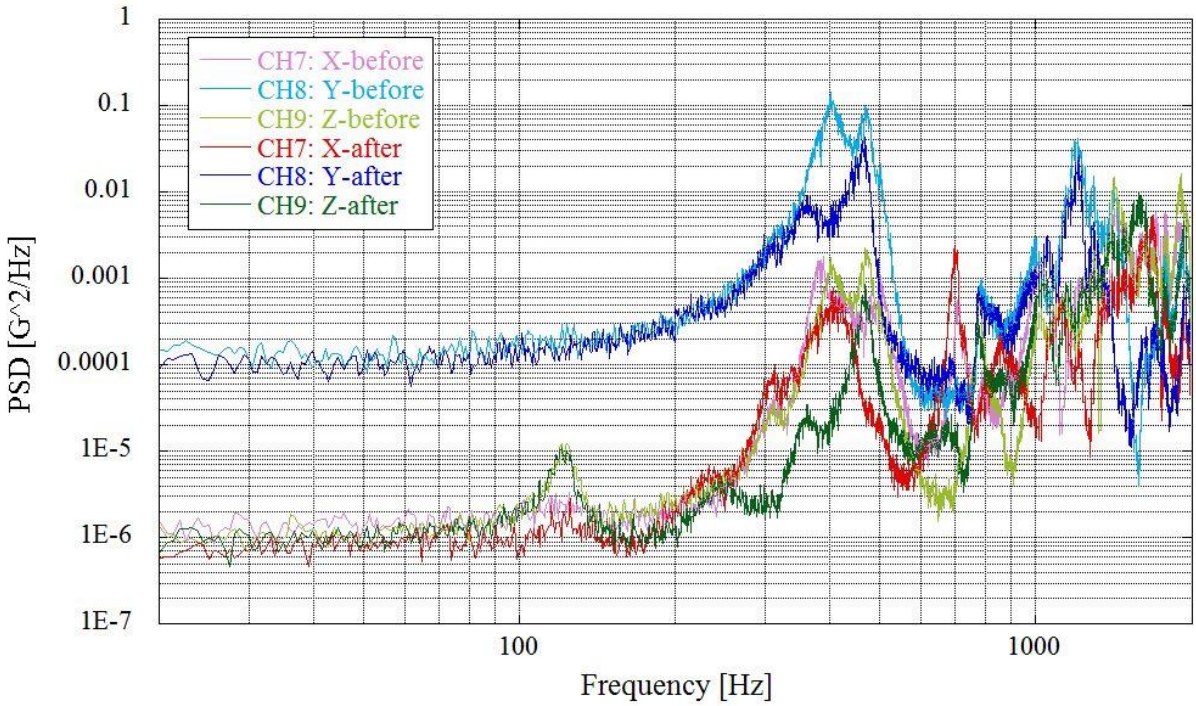


Figure 10.3-1 Modal survey for Y axis (before and after Random QT, all axis)

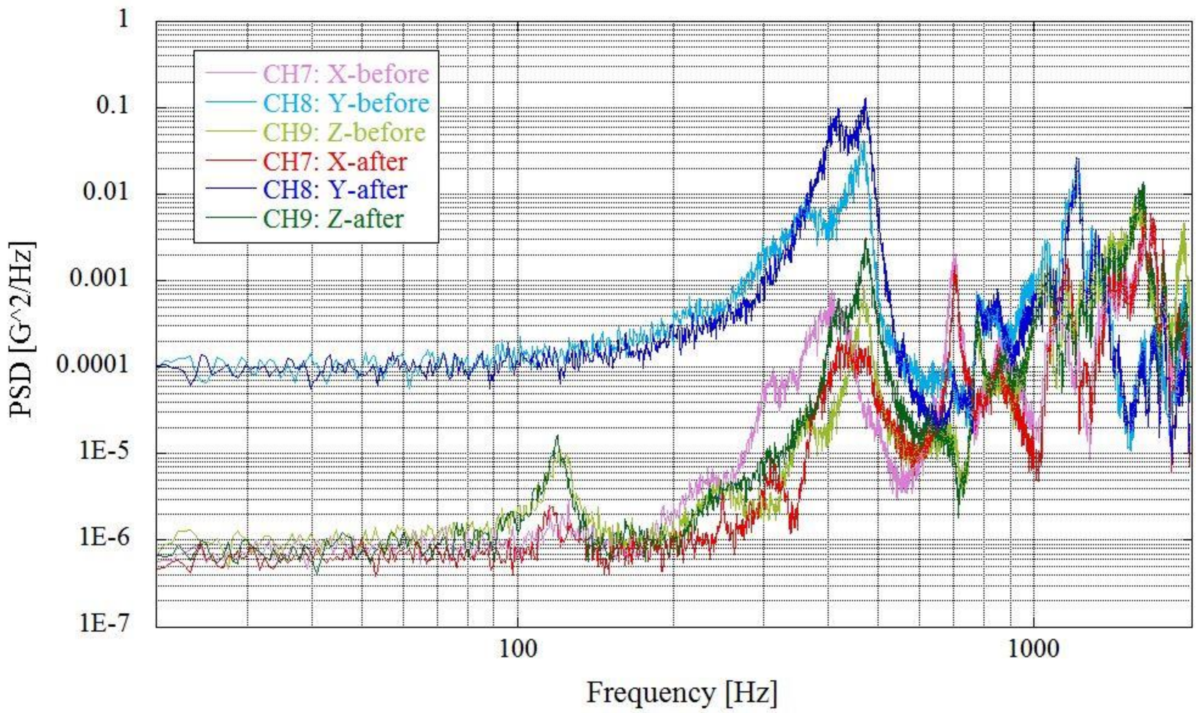


Figure 10.3-2 Modal survey for Y axis (before and after Sine Burst QT, all axis)

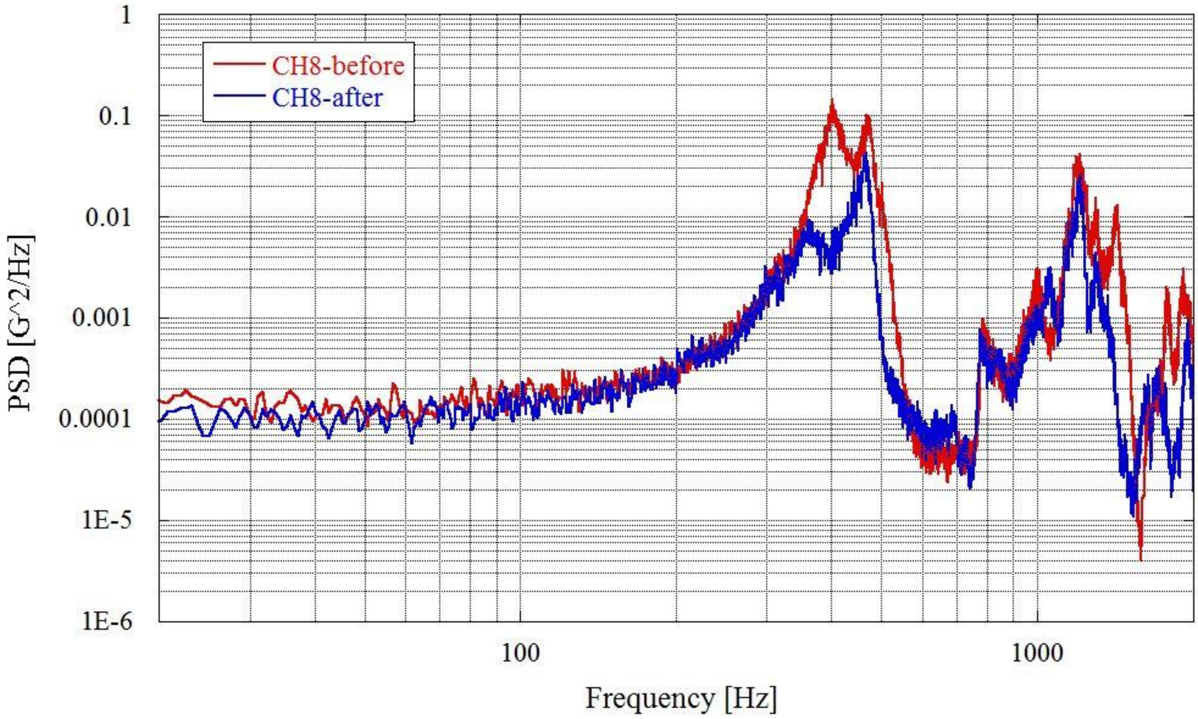


Figure 10.3-3 Modal survey for Y axis (before and after Random QT, Y axis)

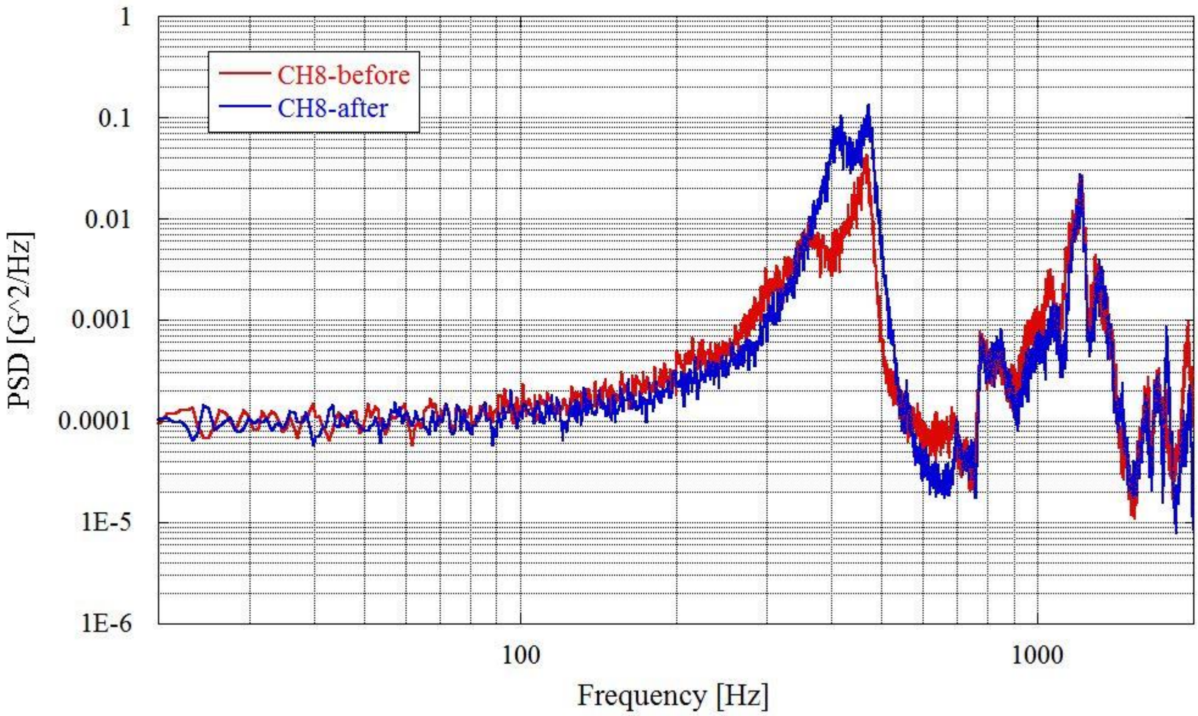


Figure 10.3-4 Modal survey for Y axis (before and after Sine Burst QT, Y axis)

10.4 Figures 10.4-1 to 10.4-4 show measurement data (during Z axis excitation).

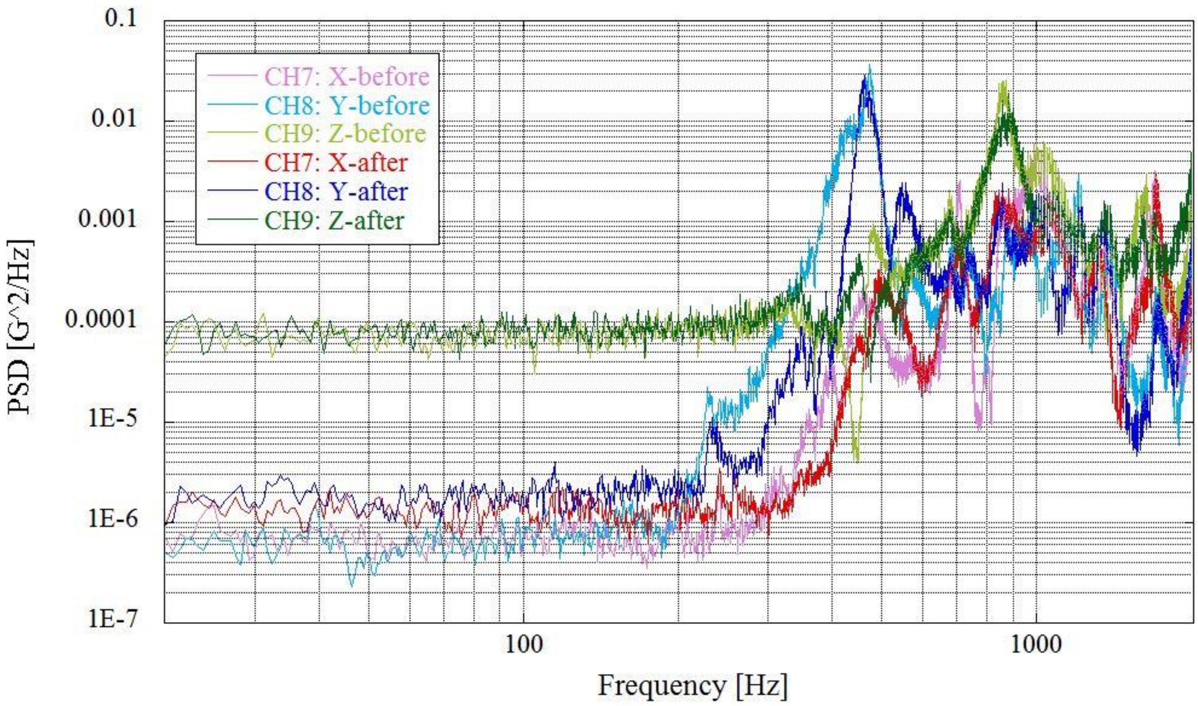


Figure 10.4-1 Modal survey for Z axis (before and after Random QT, all axis)

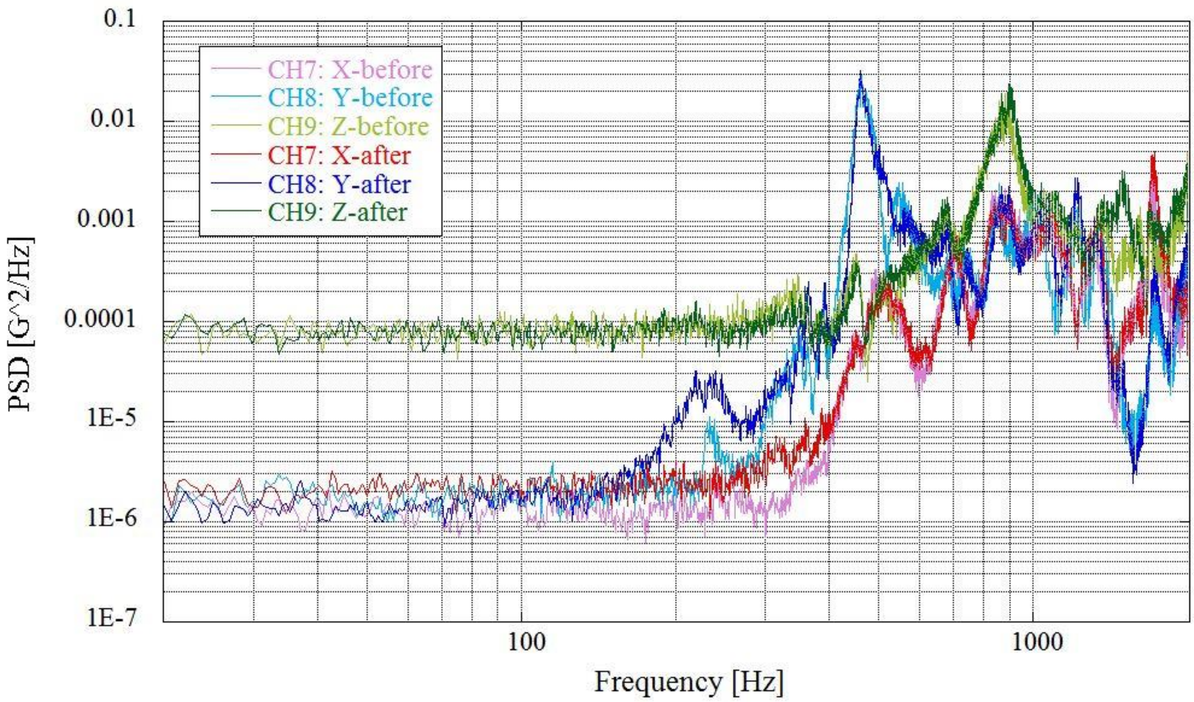


Figure 10.4-2 Modal survey for Z axis (before and after Sine Burst QT, all axis)

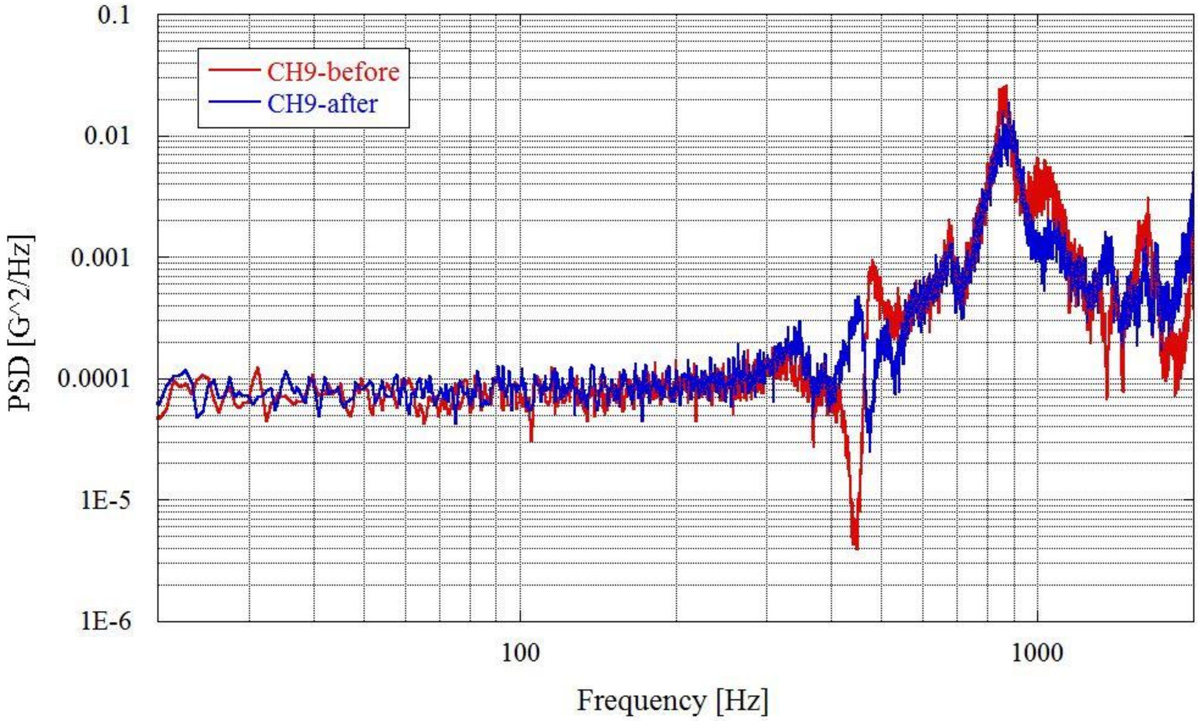


Figure 10.4-3 Modal survey for Z axis (before and after Random QT, Z axis)

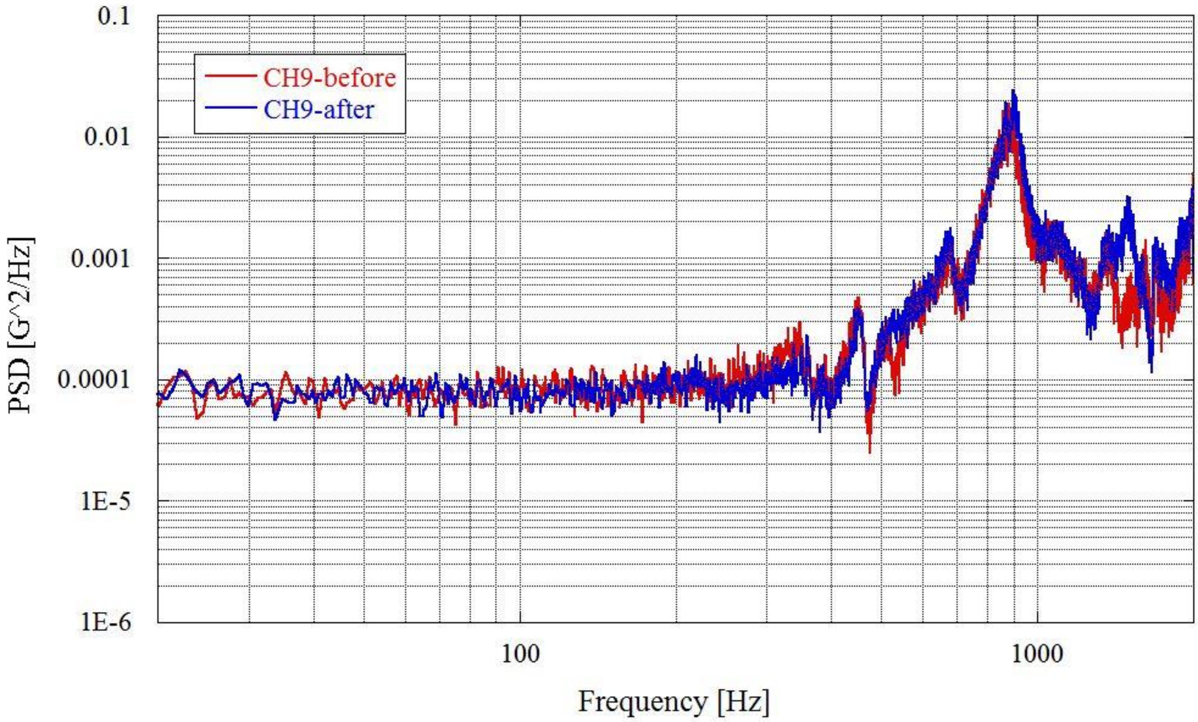


Figure 10.4-4 Modal survey for Z axis (before and after Sine Burst QT, Z axis)

11. Discussion

Table 11-1 Discussion to specific results

Test Axis	Satellite Axis	Result	Discussion	<100Hz
X-axis	X-axis	No shift in frequency in Random and Sine Burst	-	Yes
	Y-axis	Amplitude of natural frequency of higher than X-axis	This can happen at times. Dr. Masui states that this is a non-issue.	Yes
	Z-axis	No shift in frequency in Random and Sine Burst	-	Yes
Y-axis	X-axis	Slight shift in frequency in both Random and Sine Burst. Right shift corresponds to natural frequency increasing.	The test article is more compact. Visual inspection showed nuts were loose.	Yes
	Y-axis	Slight shift in frequency in Random test however, the graph shifted back to original frequency after Sine Burst	The test article's natural frequency returned back to original frequency.	Yes
	Z-axis	No shift in frequency in Random and Sine Burst	-	Yes
Z-axis	X-axis	Slight shift in frequency in both Random and Sine Burst. Right shift corresponds to natural frequency increasing. This shows the test article was more compact than before	The test article is more compact. Visual inspection showed nuts were loose.	Yes
	Y-axis	Amplitude of natural frequency of higher than Z-axis	This can happen at times. Dr. Masui states that this is a non-issue.	Yes
	Z-axis	No shift in frequency in Random and Sine Burst	-	Yes

The natural frequency in all axis remained <100 Hz for all axis and fulfils JAXA's requirement. Additionally, since BIRDS-3 satellite will be part of the cargo to ISS, the test conditions are much higher than true environment.

12. Conclusion

The BIRDS-3 EM underwent Random Vibration and Sine Burst test in the X, Y and Z axis. Although no shift in the Pod's natural frequency was observed, there were slight frequency shift at the satellite's X-axis. The details have been discussed in the previous chapter.

Visual inspection shows no visible deformation or damage to the main structure and the solar cells of BIRDS-3. The antenna did not deploy during the testing. The satellite remained in an OFF state throughout. Functional testing, including the camera test did not show any difference.

Appendix

1) Compare between Satellite and Pod measurement (during X axis excitation).

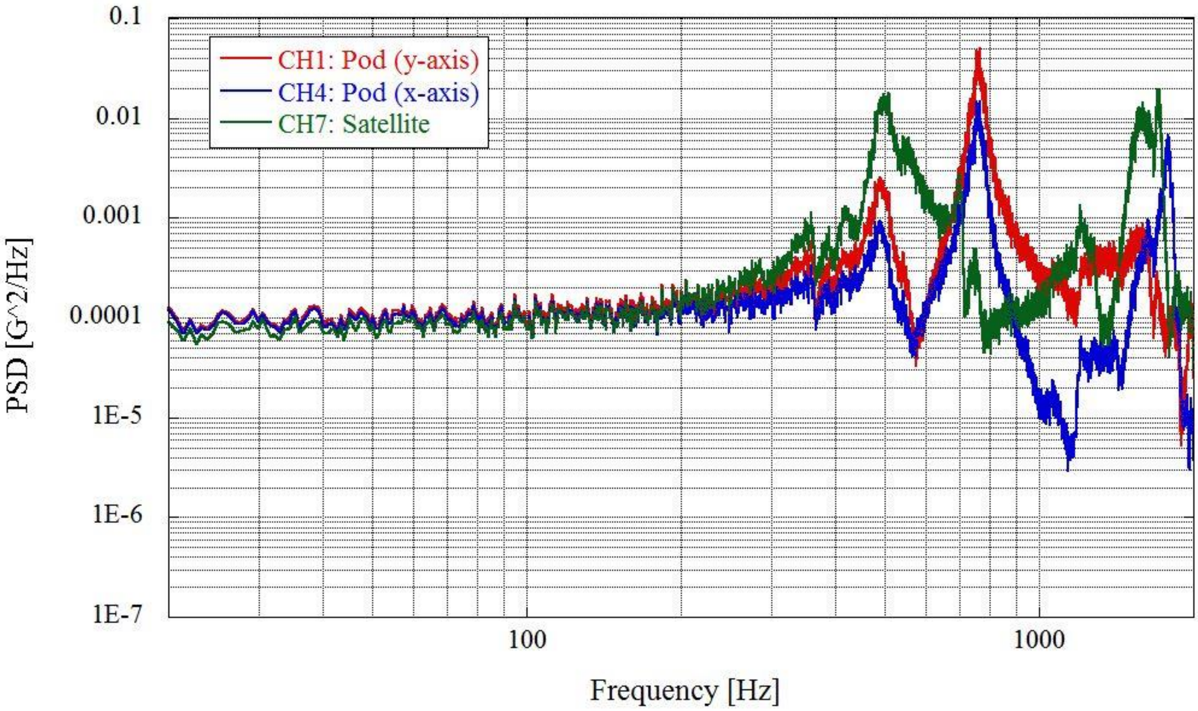


Figure Apx.1_1 Modal survey for X axis (before random QT)

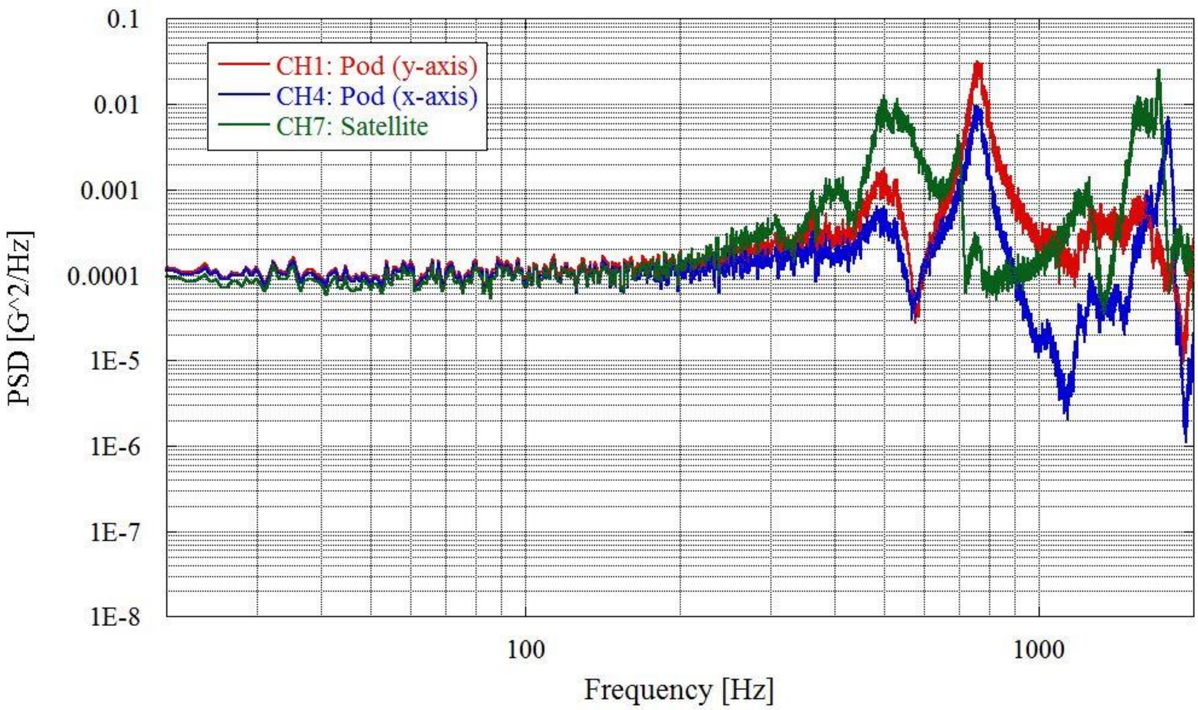


Figure Apx.1-2 Modal survey for X axis (after random QT)

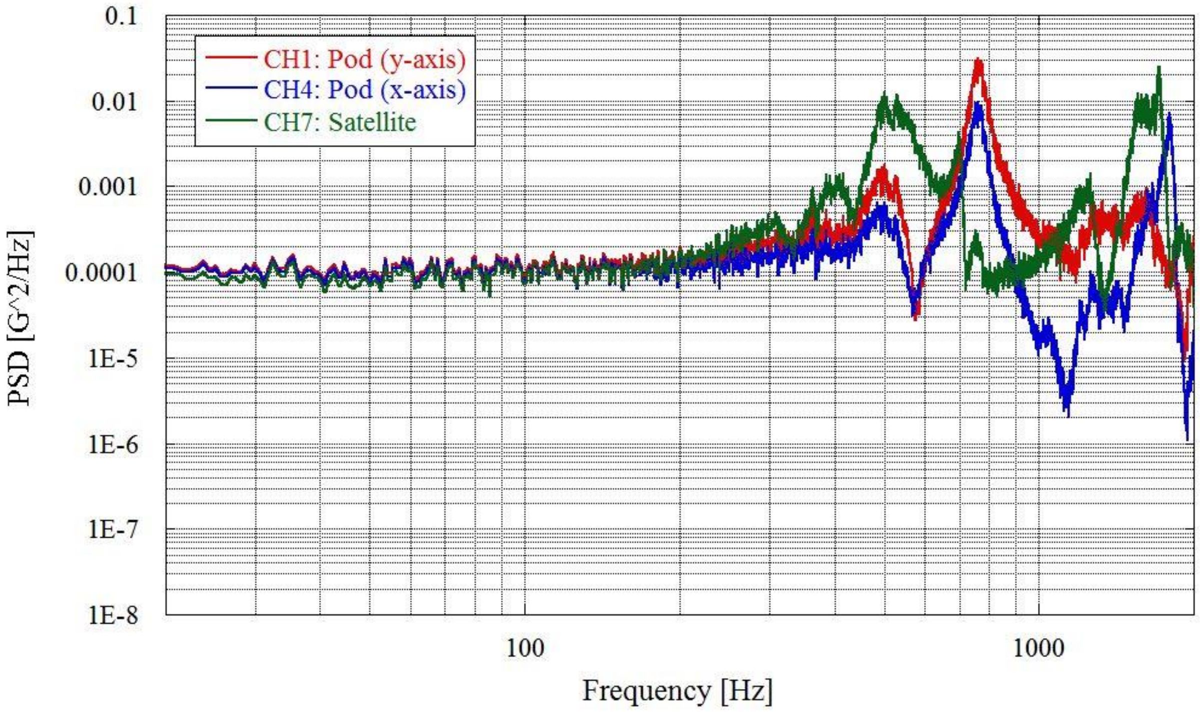


Figure Apx.1-3 Modal survey for X axis (after sine burst QT)

2) Compare between Satellite and Pod measurement (during Y axis excitation).

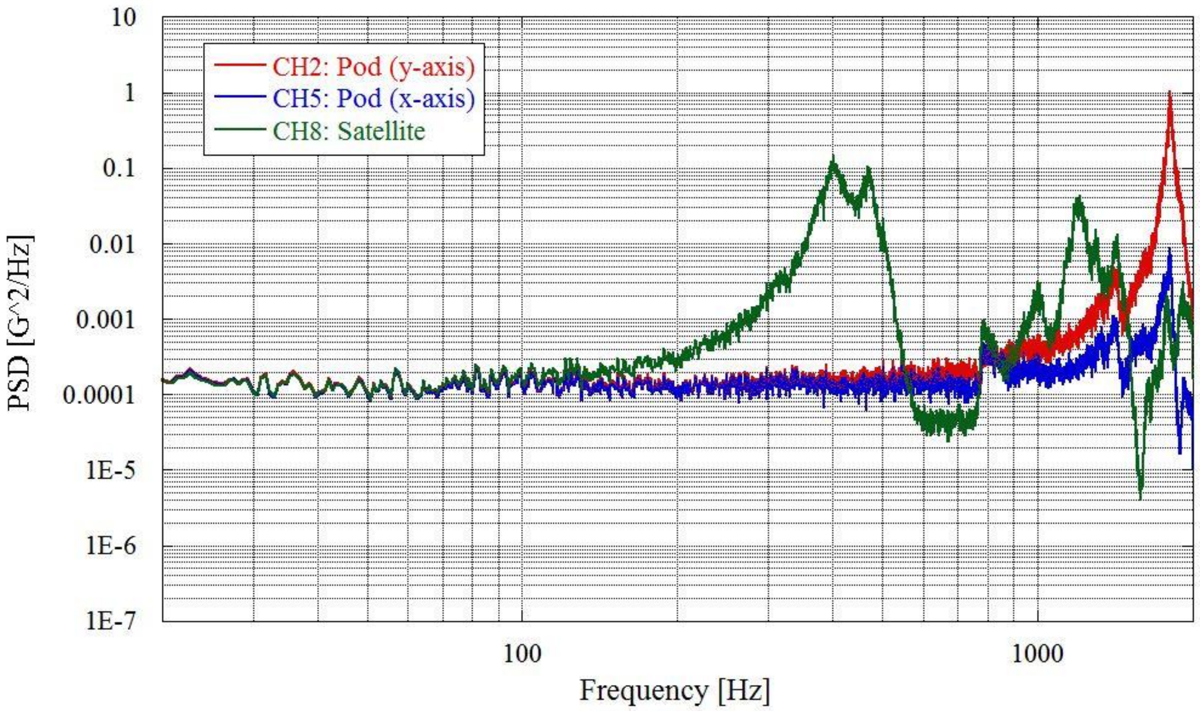


Figure Apx.2_1 Modal survey for Y axis (before random QT)

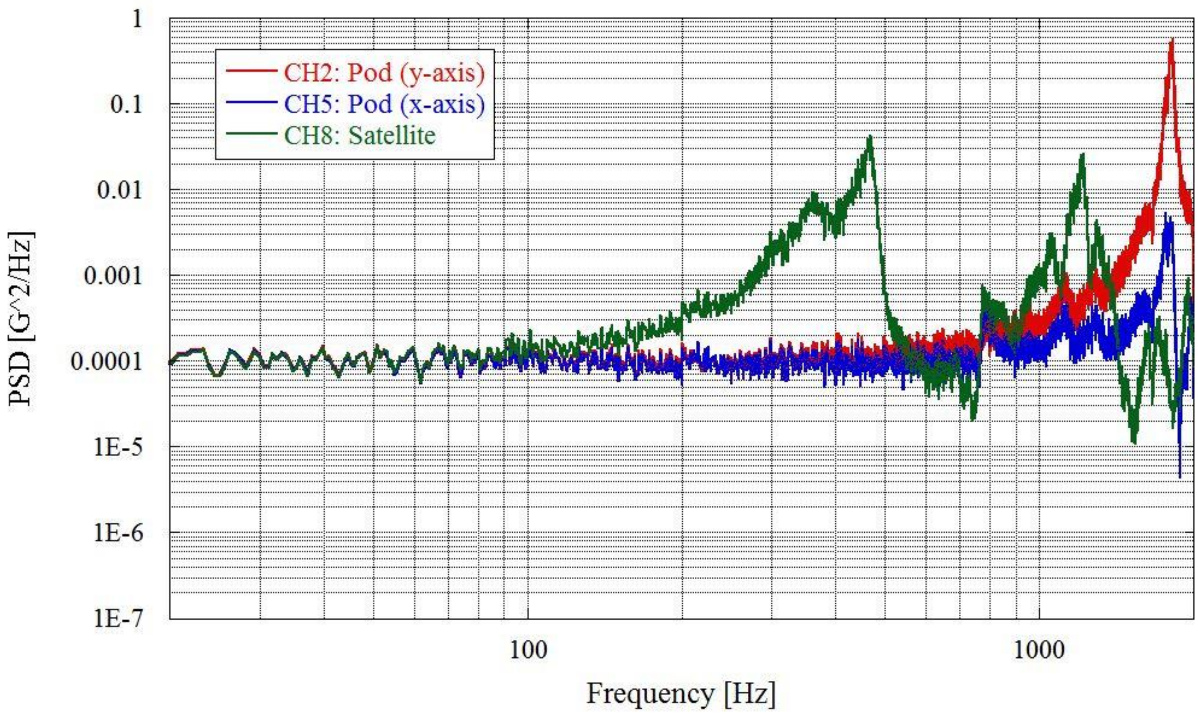


Figure Apx.2-2 Modal survey for Y axis (after random QT)

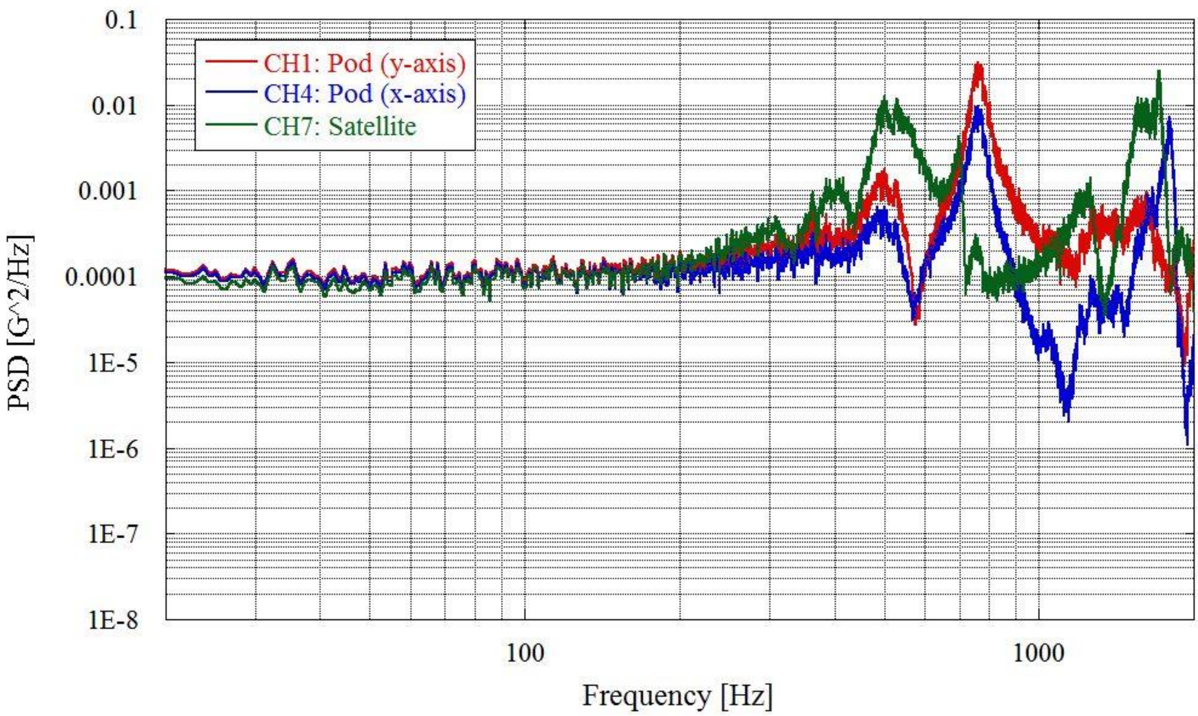


Figure Apx.2-3 Modal survey for Y axis (after sine burst QT)

3) Compare between Satellite and Pod measurement (during Z axis excitation).

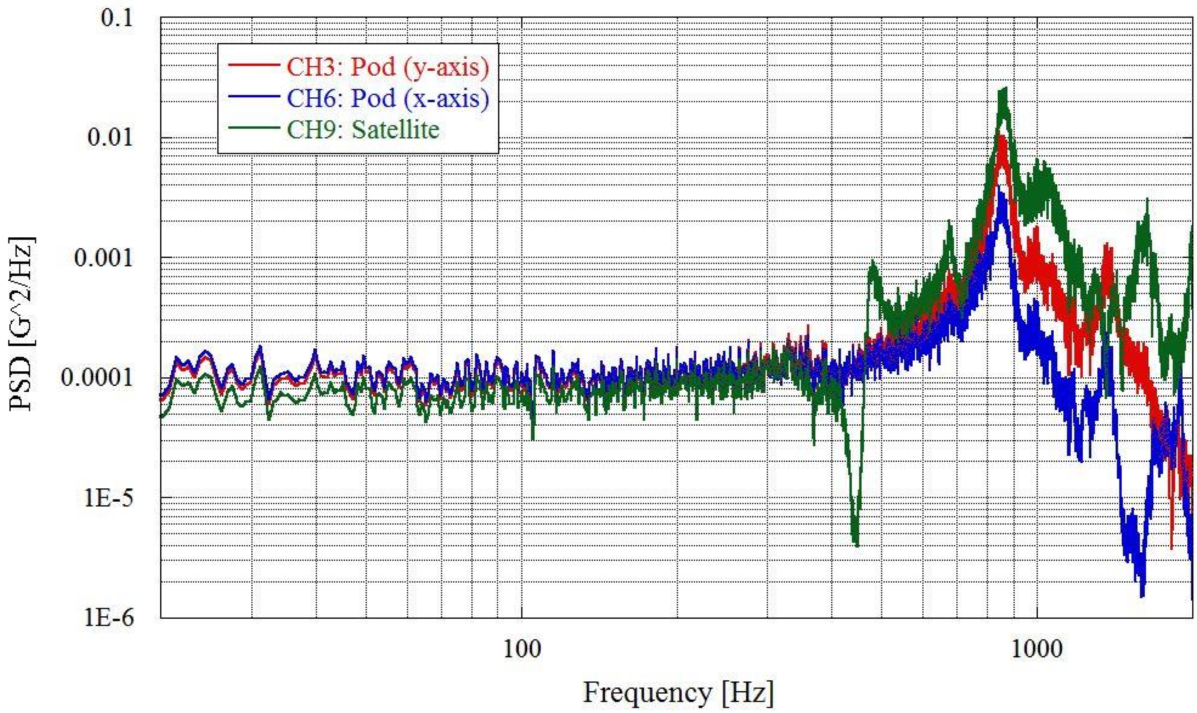


Figure Apx.3_1 Modal survey for Z axis (before random QT)

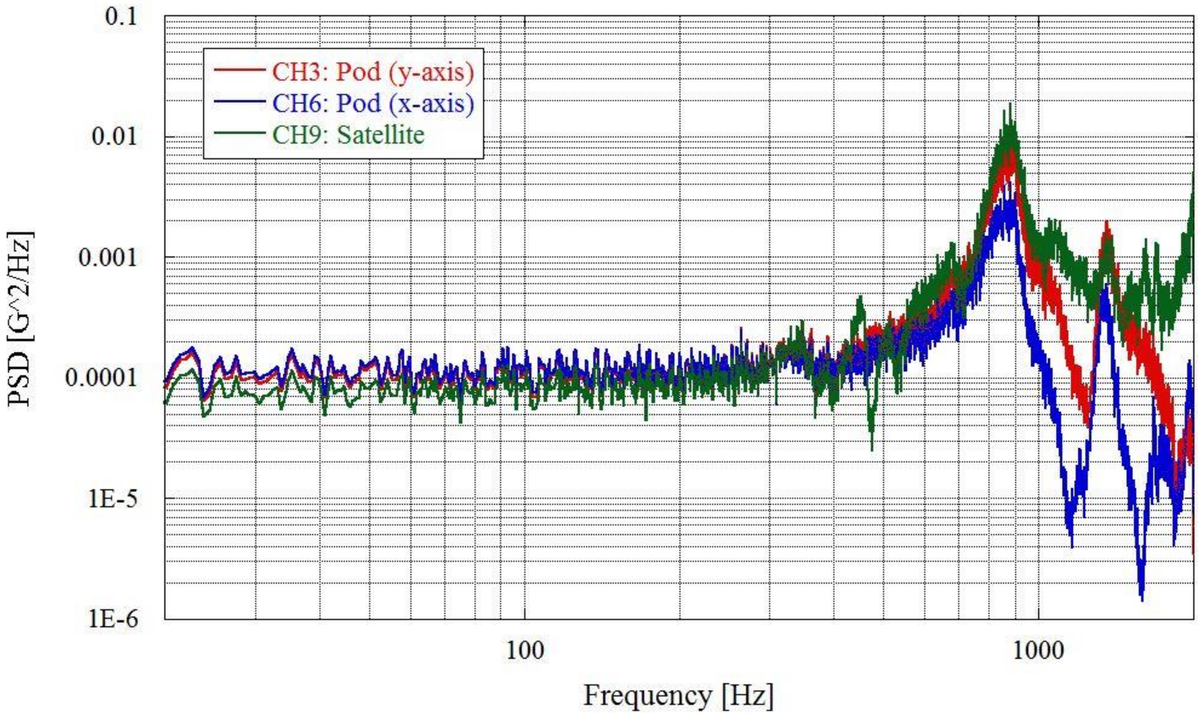


Figure Apx.3-2 Modal survey for Z axis (after random QT)

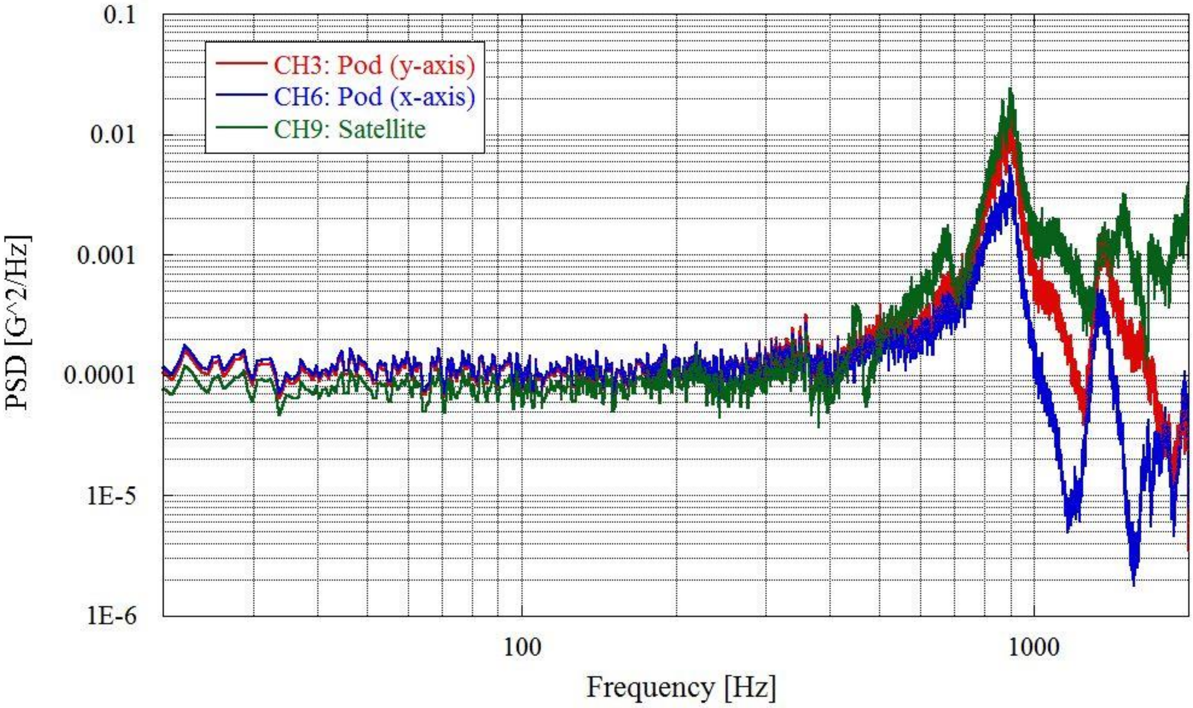


Figure Apx.3-3 Modal survey for Z axis (after sine burst QT)