

DEVELOPMENTAL HALT Report R-00000371-2

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**denotes test or test parameters outside scope of ISO17025 accreditation*

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1.0 Objective

Poor reliability, low MTBF, frequent field returns, high in-warranty costs, and customer dissatisfaction are often the result of design and/or process weaknesses, even if a product has successfully passed qualification tests and burn-in.

The product was subjected to the HALT process to uncover design and/or process weaknesses. During the HALT process, the product was subjected to progressively higher stress levels brought on by thermal dwells, vibration, rapid temperature transitions and combined environments.

Throughout the HALT process, the intent was to subject the product to stimuli well beyond the expected field environments to determine the operating and destruct limits of the product. Failures, which typically show up in the field over a period of time at much lower stress levels, are quickly discovered while applying high stress conditions over a short period of time.

HALT is primarily a margin discovery process. In order to ruggedise the product, the root cause of each of failure needs to be determined and the problems corrected until the fundamental limit of the technology for the product can be reached. This process will yield the widest possible margin between product capabilities and the environment in which it will operate, thus increasing the product's reliability, reducing the number of field returns and realizing long-term savings.

The operating and destruct limits discovered during HALT on these units could be used to develop an effective Highly Accelerated Stress Screen (HASS) for manufacturing which will quickly detect any process flaws or new weak links without taking significant life out of the product. The HASS process will ensure that the reliability gains achieved through HALT will be maintained in future production.

*denotes test or test parameters outside scope of ISO17025 accreditation as per service proposal S-00000371.

2.0 Executive Summary

HALT testing was performed on four Cobra Cure FX2™ UV LED curing system. During the HALT process, the goal was to find the operating and destruct limits for the units tested using thermal step stress, vibration step stress, and combined environment of temperature and multi-axis, 6 degree-of-freedom vibration. Once these limits were determined, the goal was to fix the weak links and stress even further to expand the limits as much as possible. The operating and destruct limits are summarized in table 1. See section 7.0 for a detailed discussion of failures. The HALT testing exposed weaknesses under specific operating conditions. The customer should determine if these weaknesses require an engineering solution or if the performance is sufficient for their desired specification level.

2.1 Cold Thermal Step Stress

The units were functionally tested at each dwell down to -60°C and were powered throughout the cold thermal step stress test as shown in figures 3 Cold step stress profile from chamber and figure 6 Cold step stress component profile.

The customer confirmed that at temperature below 5°C the FX2 UV LED may switch off. This is expected as a result of built in software limits on the UV LED on the units. The hardware within the units continued to operate internally.

During the cold thermal step stress test it was found that at -10°C the 4 FX2 units UV LED turned off. The hardware within the units continued to operate internally without any issue as far as -60°C when it was decided to stop at this dwell and return to ambient conditions.

As the chamber was returned to 20°C all units resumed normal operation by the time the chamber reached 10°C and the UV LED switched on again as expected operated within specification and no observable issues were recorded.

2.2 Hot Thermal Step Stress

The units were functionally tested at each dwell up to 80°C, as shown in figures 4 Hot step stress profile from chamber and figure 7 Hot step stress component profile. . The units were powered throughout the testing and monitored for any issues. A functional test was performed at each dwell.

The customer confirmed that the UV LED may switch off in the FX2 at temperatures above 55°C. This is expected as a result of built in software limits on the UV LED on the units. The hardware within the units continued to operate internally without any issue.

It was observed that at 70°C 2 of the FX2 UV LEDs switched off, however when the power supply was turned off for a few minutes and on again all units powered up with UV LEDs.

When the chamber was ramped to +80°C the UV LED turned off on all units after 1 minute.

When the chamber was returned to 50°C all of the units (UV LED) returned of normal operation. On return to 20°C all of the units continued to operate as expected within specification and no observable issues were recorded.

2.3 Rapid thermal transitions

The units were powered throughout the testing and monitored for any issues. See figures 5 Rapid thermal transitions chamber profile and figure 8 Rapid thermal transitions component profiles. A functional test was performed at each dwell.

During the dwell at -20°C some of the UV LED were off and intermittent for the FX2 units, however all units UV LED recovered fully on the ramp to 60°C at approx. 0-5°C

It was expected that at temperature below 5°C and above 55°C the FX2 UV LED may switch off. This is expected as a result of built in software limits on the UV LED on the units. The hardware within the units continues to operate internally without any issue.

On return to 20°C the units continued to operate as expected within specification and no observable issues were recorded.

2.4 Vibration Step Stress

The cameras were functionally tested at each vibration dwell up to 40G.

The units were powered throughout the testing and monitored for any issues. A functional test was performed at each dwell.

At 30G it was also observed that there were loose screws in the heads of an FX2 395 (188256). These were tightened and testing continued.

At 40G a flexi cable became loose internally on an FX2 365 unit. When the unit was examined the cable was sideways but not out of its position. It was also found that two of the FX2 365 had cover damage where the cover was damaged at the centre of the unit behind the heatsink.

All the units continued to operate as expected within specification and no observable issues were recorded.

2.5 Combined Environmental Stress

The units were powered throughout the testing and monitored for any issues. A functional test was performed at each dwell. The units operated from -20°C to +60°C and to 40g.

It was expected that at temperature below 5°C and above 55°C the FX2 UV LED may switch off as a result of built in software limits on the UV LED on the units. The hardware within the units continued to operate internally without any issue.

On return to 20°C the units continued to operate as expected within specification and no observable issues were recorded

On completion of testing the units were visually examined and the following observations noted:

- FX2 365 (188138) and a FX2 365 (188139) had cracked covers
- FX2 395 (188256) and FX2 395 (188257) were OK

3.0 Operating and Destruct Limits

Stress Type	Chamber Setpoint Level
Temp LOL	-60°C
Temp LDL	>-60°C
Temp UOL	+60°C
Temp UDL	>80°C
Thermal Transitions	-20°C to +60°C
Vibration OL	30G
Vibration DL	>40G
Combined OL	-20°C to +60°C and 30G
Combined DL	>-60°C to >+80°C and 40G

Table 1: Summary of Operating and Destruct Limits

Notes:

1. All temperature and vibration values are chamber set points. See Section 7 and the Appendix for product levels.
2. LOL / LDL = Lower Operating / Destruct Limit. UOL / UDL = Upper Operating / Destruct Limit. For vibration there is an upper limit only.
3. Operating Limit is defined as the point at which the product is still fully functioning but when the applied stress is increased, the product is no longer function.
4. Destruct Limit is defined as the point at which the product still returns to full operation when the applied stress is decreased to within the operating limit but when the applied stress is increased the unit fails to return to operation when the applied stress is returned to within the operating limit.
5. When the limit is preceded by a ">" or "<" sign it indicates that we stopped prior to a failure, either because of a limitation of the chamber, the test setup, or per customer request.
6. The limits shown are the worst case limits. In other words, the limits for the product that had the lowest limits of all units tested under that stress. These limits reflect the product limits before any modifications.

4.0 Halt process

The test procedure followed is outlined in the ARTC service proposal noted on the front page of this report. Any deviations from this procedure are noted below.

5.0 Halt Setup

5.1 Product Identifiers

The serial number of the units subjected to the HALT process and the date these units were received are shown in table 2.

Unit	Type	Model	Serial	Test	Date Received
1	Cobra Cure FX2 TM UV LED Curing system	365	188138	Cold Thermal Step Stress Hot Thermal Step Stress Rapid Thermal Transitions Vibration Step Stress Combined Environment	04 th Oct 2016
2			188139		
3		395	188256		
4			188257		

Table 2: Product Identifiers

5.2 Fixturing and Airflow

The units were placed in the environmental chamber and secured to using overhead clamps to the vibration plate.

Air from the chamber plenum was directed onto the units. The fixture was designed to maximize both transmission of energy from the vibration table to the product and thermal transition rates, as well as to help maintain consistent temperatures on all the components inside the test units.

5.3 Test Setup

The units were powered using two customer supplied DC power supplies at 24VDC, located externally beside the halt chamber. The units were on full power for the step stress tests, thermal cycling, and combined environmental tests and on reduced power for the vibration step stress tests. Power harnesses were fed through the port hole of the chamber where they were then connected inside onto the cameras under test.

The function test involved performing the following steps:

- Ensure the chamber has stabilised at the temperature / vibration level
- Observe any issues such as UV LED operation, unit hardware still active, and voltage outputs observed, and record any issues noted
- During each dwell a functional test was performed and any observations noted.

5.4 Description of Test Equipment

Description	Manufacturer	Model	S/N	Cal Due
Thermal & Vibration Test Chamber	QualMark	OVS 2.5	2604980254	23 rd Mar 2017
Data Acquisition Unit	Hewlett Packard	34970A	US37038352	22 nd Apr 2017
Data Logger Thermocouple	RS	Type T	ANO1563	1 st Nov 2016
Data Logger Thermocouple	RS	Type T	ANO2187	1 st Nov 2016
Data Logger Thermocouple	RS	Type T	ANO2194	1 st Nov 2016
Data Logger Thermocouple	RS	Type T	ANO2200	1 st Nov 2016
Data Logger Thermocouple	RS	Type T	ANO1345	1 st Nov 2016
Data Logger Thermocouple	RS	Type T	ANO2245	1 st Nov 2016
Data Logger Thermocouple	RS	Type T	ANO2199	1 st Nov 2016
Chamber Thermocouple	RS	Type T	ANO1983	1 st Nov 2016
Chamber Thermocouple	RS	Type T	ANO1373	1 st Nov 2016
Chamber Thermocouple	RS	Type T	ANO1535	1 st Nov 2016
Accelerometer Voltage Mode	Dytran	3030C1	10119	13 th Sep 2017
Cable Assembly	Dytran	6019B10	ANO0997	13 th Sep 2017
Charge Amplifier	Dytran	4705M16	3569	13 th Sep 2017
Spectrum Analyser	Data Physics	DP240D	20995	28 th Mar 2017
Accelerometer	Dytran	3035B1G	7238	12 th May 2017

Table 3: Test Equipment

6.0 Data Collection

Thermocouples were attached to the units under test to monitor temperature changes used for data collection in addition to a product and air which were located on the surface and above the unit. The thermocouples remained in place for the cold, hot step tests and the thermal cycling. The product thermal response at each thermocouple location was recorded at each level of thermal stress. See section 10.0 for thermal graphs.

Accelerometers were placed at reference points on the product during vibration step stress. The product vibration response was recorded at each level of vibration stress.

Channel	Location or Description
1	Main IC
2	PCBA (product)
3	U1B IC
4	Outside front of fan (air)
5	Heatsink
6	L1B

Table 4: Datalogger Channel Assignment

Channel	Placement
Product (control)	Internal PCBA
Air	Air back of Unit
Honeywell	Wall of chamber

Table 5: OVS Control System Thermocouple Placement

Channel	Location	Axis
1	Top corner of Unit Cover	Z

Table 6: Accelerometer Placement

7.0 HALT Results

7.1 Thermal Step Stress

The units were subjected to cold thermal step stress beginning at +20°C. The chamber was then decreased in 10°C increments until -60°C. Once the thermocouples located on the units stabilized, the unit remained at each set point for a minimum of 15 minutes. A function test was performed at the end of each dwell. Once cold thermal step stress was completed, the unit was returned to +30°C and remained there until the thermocouples located on the unit stabilized.

Hot thermal step stress began at a setpoint temperature of +20°C. The chamber was then increased in 10°C increments until +80°C thereafter. Once the thermocouples located on the unit reached the setpoint temperature, the unit remained at that setpoint for 15 minutes.

The results of thermal testing are summarized in Table 7, 8, 9 and 10.

Setpoint	Function Test Results	Notes
+20°C	OK	1
10°C	OK	1
0°C	OK	1
5°C	OK	1,2
-10°C	See Below	1,3
5°C	OK	1,2
-20°C	See Below	1,3
-30°C	See Below	1,3
-40°C	See Below	1,3
-50°C	See Below	1,3
-60°C	See Below	1,3
20°C	See Below	1,4

Table 7: Cold thermal Step Stress Results

Notes:

1. The units were powered throughout the testing and monitored for any issues. A functional test was performed at each dwell.
2. At temperature below 5°C the FX2 UV LED may switch off. This is expected as a result of built in software limits on the UV LED on the units. The hardware within the units continued to operate internally without any issue.
3. At -10°C the 4 FX2 units UV LED turned off.
4. When the chamber was returned to 20°C the all units operated as normal and the UV LED switched on again.

Setpoint	Function Test Results	Notes
+30°C	OK	1
+40°C	OK	1
+50°C	OK	1
+60°C	See Below	1,2
+70°C	See Below	1,3
+80°C	See Below	1,3,4
+50°C	See Below	1,5
+20°C	OK	1,6

Table 8: Hot Thermal Step Stress Results

Notes:

1. The units were powered throughout the testing and monitored for any issues. A functional test was performed at each dwell.
2. At temperature above 55°C the FX2 UV LED may switch off. This is expected as a result of built in software limits on the UV LED on the units. The hardware within the units continued to operate internally without any issue.
3. At 70°C two of the FX2 switched off. When the power supply was turned off for a few minutes and on again all of the units powered up with UV LED.
4. After 1 minute of +80°C the UV LED turned off on all units.
5. When the chamber was returned to 50°C all of the units (UV LED) returned of normal operation.
6. On return to 20°C the units continued to operate as expected within specification and no observable issues were recorded.

7.2 Rapid Thermal Transitions

The units under test was subjected to five and a half temperature cycles from +60°C to -20°C at an average thermal transition rate of 55°C per minute. The average thermal transition rate is computed from the average transition of all the product temperature response thermocouples. The rate is computed through the centre region of the entire transition, which discounts 20% at each end of the transition.

Cycle	Setpoint	Function Test Results	Notes
1	20°C	OK	1
1	60°C	See Below	1,2
1	-20°C	See Below	1,2,3
2	60°C	See Below	1,2
2	-20°C	See Below	1,2,3
3	60°C	See Below	1,2
3	-20°C	See Below	1,2,3
4	60°C	See Below	1,2
4	-20°C	See Below	1,2,3
5	60°C	See Below	1,2
5	-20°C	See Below	1,2,3
5	60°C	See Below	1,2
5	20°C	OK	4

Table 9: Rapid Temperature Transitions

Notes:

1. The units were powered throughout the testing and monitored for any issues. A functional test was performed at each dwell.
2. At temperature below 5°C and above 55°C the FX2 UV LED may switch off. This is expected as a result of built in software limits on the UV LED on the units. The hardware within the units continues to operate internally without any issue.
3. During the dwell at -20°C some of the UV LED were off and intermittent for the FX2 units, however all units UV LED recovered fully on the ramp to 60°C at approx. 0-5°C
4. On return to 20°C the units continued to operate as expected within specification and no observable issues were recorded.

7.3 Vibration Step Stress

The units under test were subjected to vibration step stress beginning at a setpoint of 5 Grms with the vibration increasing in 5 Grms increments at 15 minute intervals. The results are summarized in Table 10.

Setpoint (G)	Function Test Results	Notes
5	See Below	1
10	OK	1
15	OK	1
20	OK	1
25	OK	1
30	See Below	1,2
35	OK	1
40	See Below	1,3,4
0	OK	1,5

Table 10: Vibration Step Stress Results

Notes:

1. The units were powered throughout the testing and monitored for any issues. A functional test was performed at each dwell.
2. At 30G it was observed that there were screws loose in the head of FX2 395 (188256)
3. At 40G a flexi cable became loose internally on an FX2 365 unit. When the unit was examined the cable was sideways but not out of its position.
4. At 40G it was also found that two of the FX2 365 had cover damage where the cover was damage at the centre of the unit behind the heatsink.
5. All the units continued to operate as expected within specification and no observable issues were recorded.

	Ch1	
G-Level	10Hz-2KHz	10Hz-10KHz
5	6.53	8.19
10	9.92	14.84
15	13.37	20.18
20	21.87	38.59
25	25.65	45.18
30	28.90	51.96
35	38.30	66.24
40	48.04	74.70

Table 11: Vibration Levels Measured During Vibration Step Stress (Grms)

7.4 Combined Environment

The units were subjected to temperature cycles from +60°C to -20°C at an average transition rate of 55°C per minute combined with vibration. Vibration began at a setpoint of 6Grms and incremented by 6Grms at the end of each thermal cycle. The results are summarized in Table 12.

Cycle	Temp (°C)	Vibration (Grms)	Function Test Results	Notes
1	20	0	OK	1
1	60	6	See Below	1,2
1	-20	6	See Below	1,2
2	60	12	See Below	1,2
2	-20	12	See Below	1,2
3	60	18	See Below	1,2
3	-20	18	See Below	1,2
4	60	24	See Below	1,2
4	-20	24	See Below	1,2
5	60	30	See Below	1,2
5	-20	30	See Below	1,2
5	60	30	OK	1,2
5	20	0	OK	1,3,4

Table 12: Combined Environment Results

Notes:

1. The units were powered throughout the testing and monitored for any issues. A functional test was performed at each dwell.
2. At temperature below 5°C and above 55°C the FX2 UV LED may switch off. This is expected as a result of built in software limits on the UV LED on the units. The hardware within the units continues to operate internally without any issue.
3. On return to 20°C the units continued to operate as expected within specification and no observable issues were recorded
4. On completion of testing the units were visually examined and the following observations noted:
FX2 365 (188138) and a FX2 365 (188139) had cracked covers
FX2 395 (188256) and FX2 395 (188257) were OK

8.0 Synopsis

Each of the failures found during the HALT process (see section 2.0) needs to be examined and the root cause of the failure determined. Once the root cause of each failure is determined, engineering judgment is used to determine whether corrective action should be taken to fix the problem. The product should then undergo a verification HALT to ensure that the design margins have been increased to the fundamental limit of technology and that the fixes made did not induce new failure modes. The ruggedisation of the product will not be increased unless each of the failures found during the HALT process are taken to root cause and corrective action implemented.

9.0 Vibration Template

9.1 5G Vibration Profiles

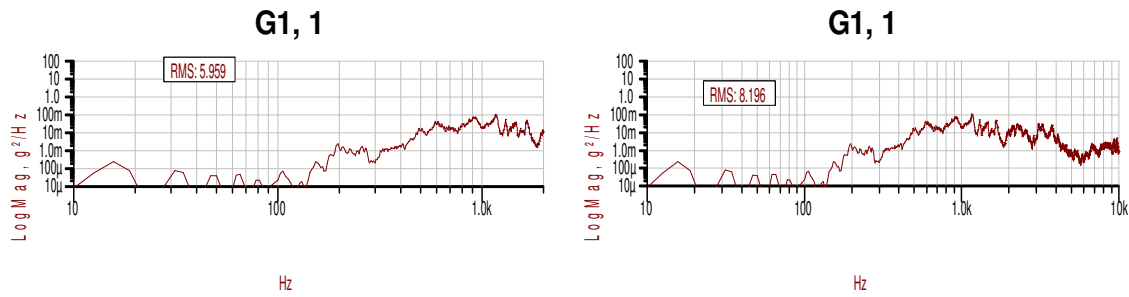


Figure 1 5G Vibration Profiles

9.2 40G Vibration Profiles

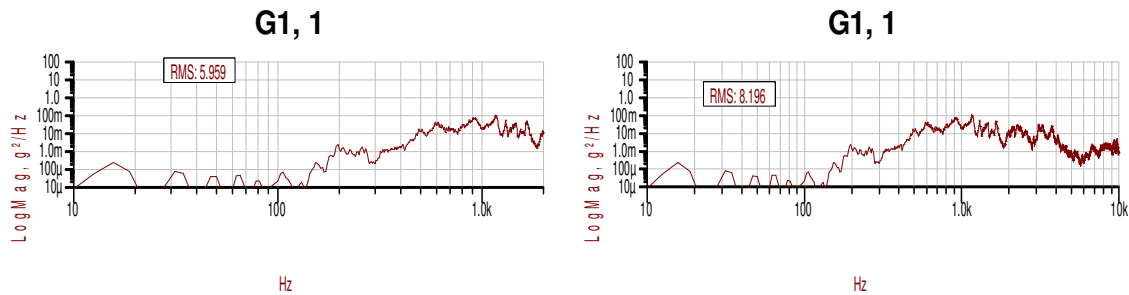


Figure 2 40G Vibration Profiles

10.0 Thermal and Vibration Graphs

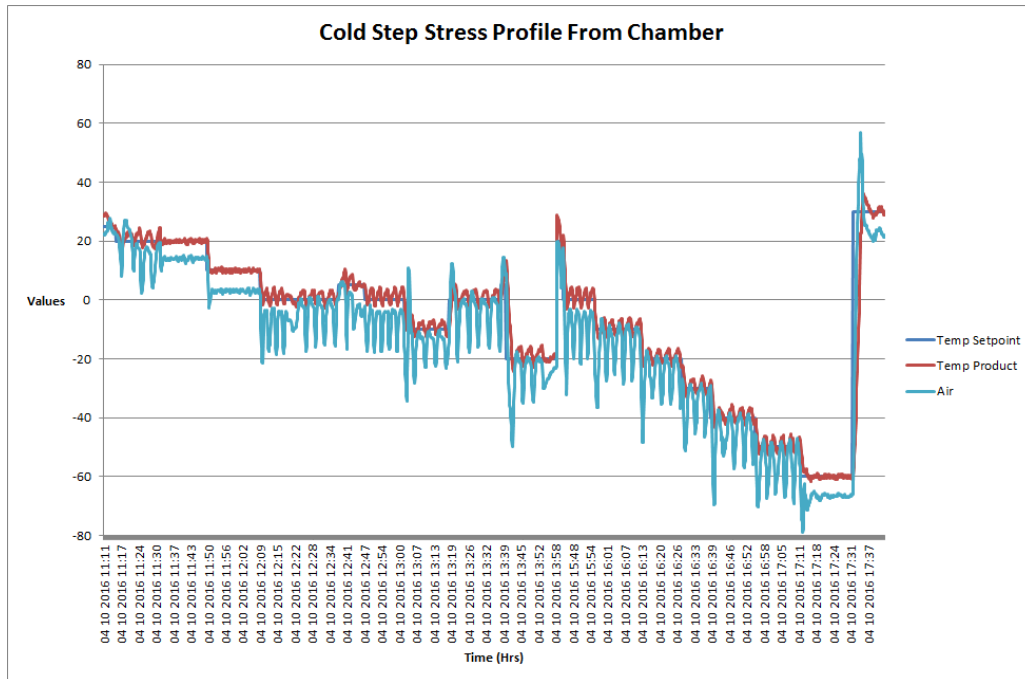


Figure 3 Cold Step Stress Profile from Chamber

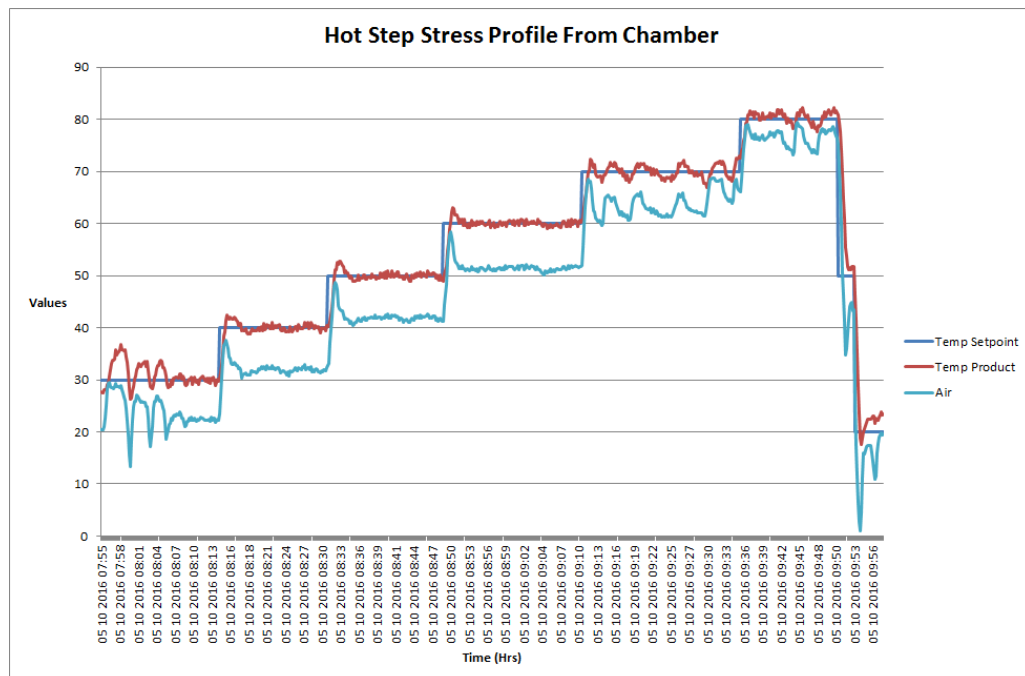


Figure 4 Hot Step Stress Profile from Chamber

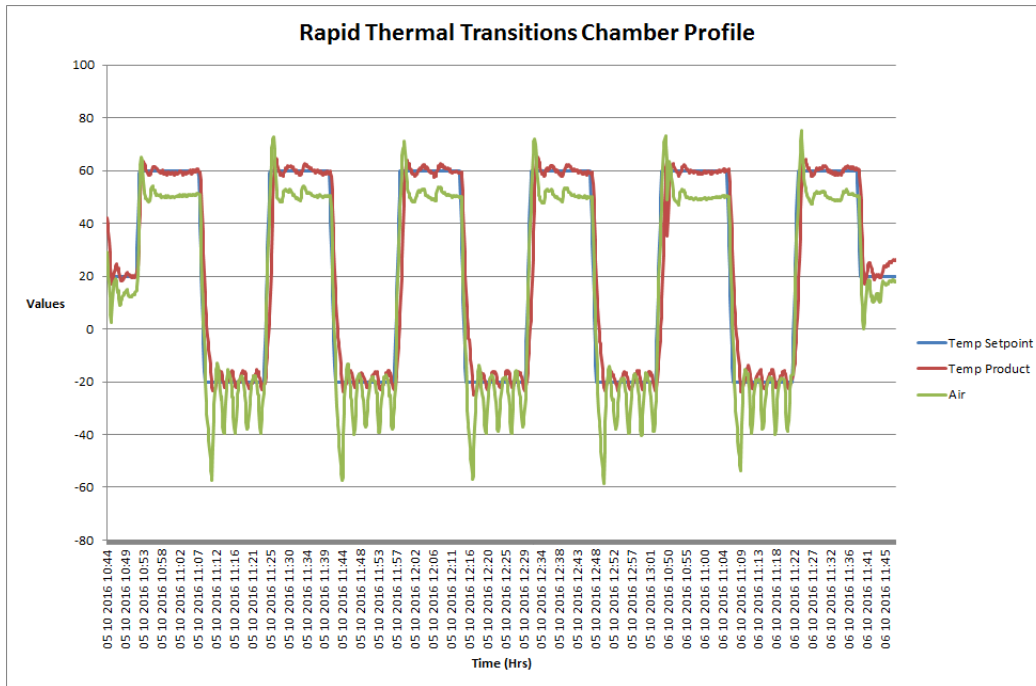


Figure 5: Rapid Thermal Transitions Chamber Profile

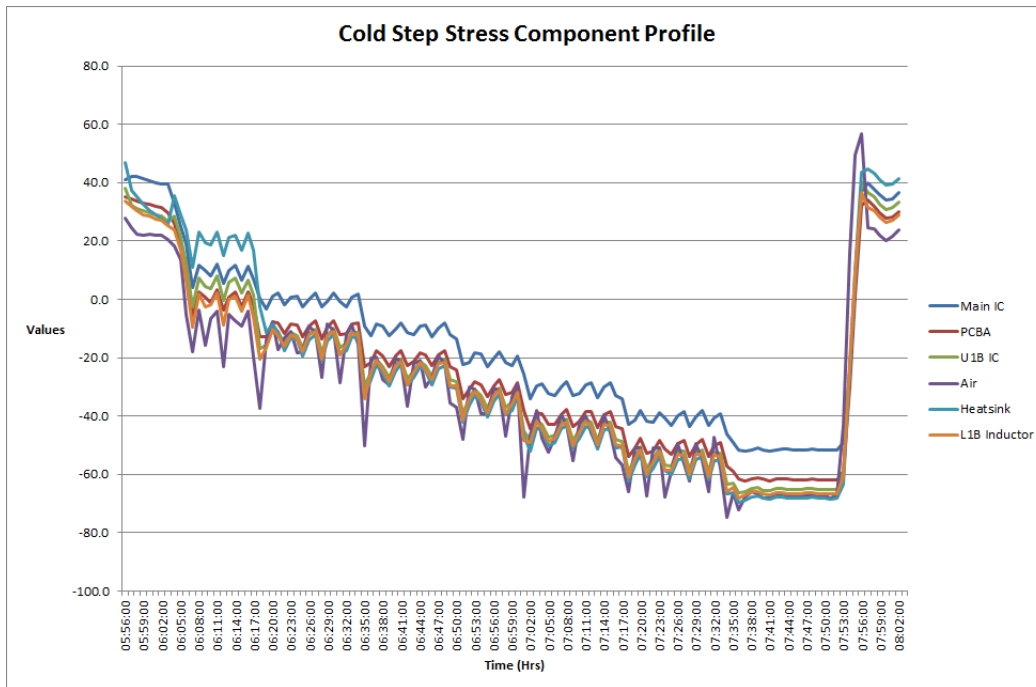


Figure 6: Cold Step Stress Component Profile

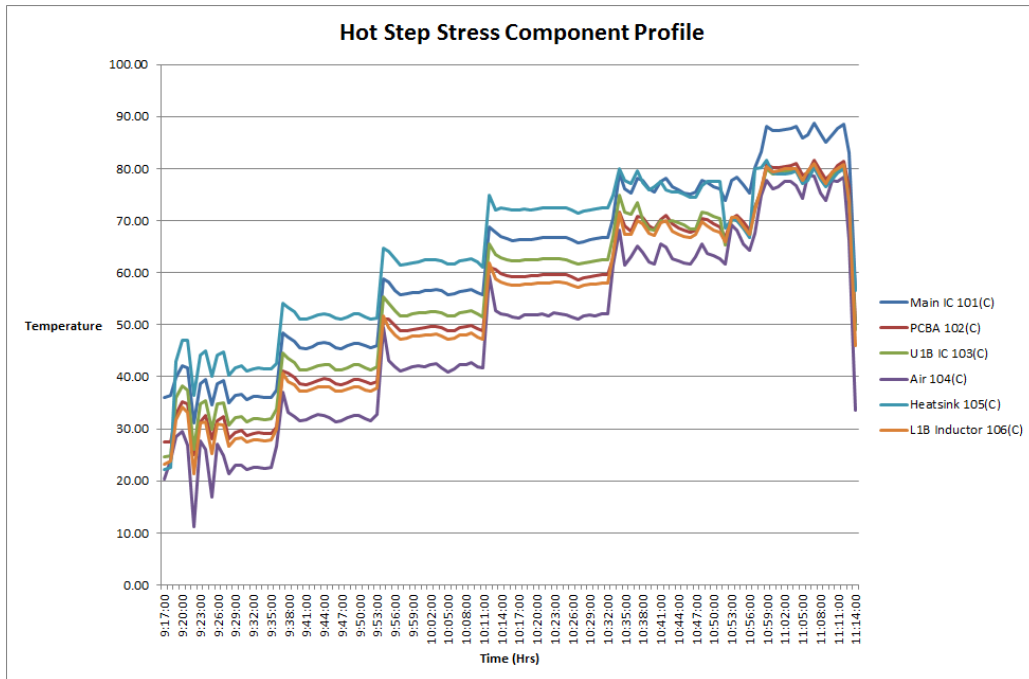


Figure 7: Hot Step Stress Component Profile

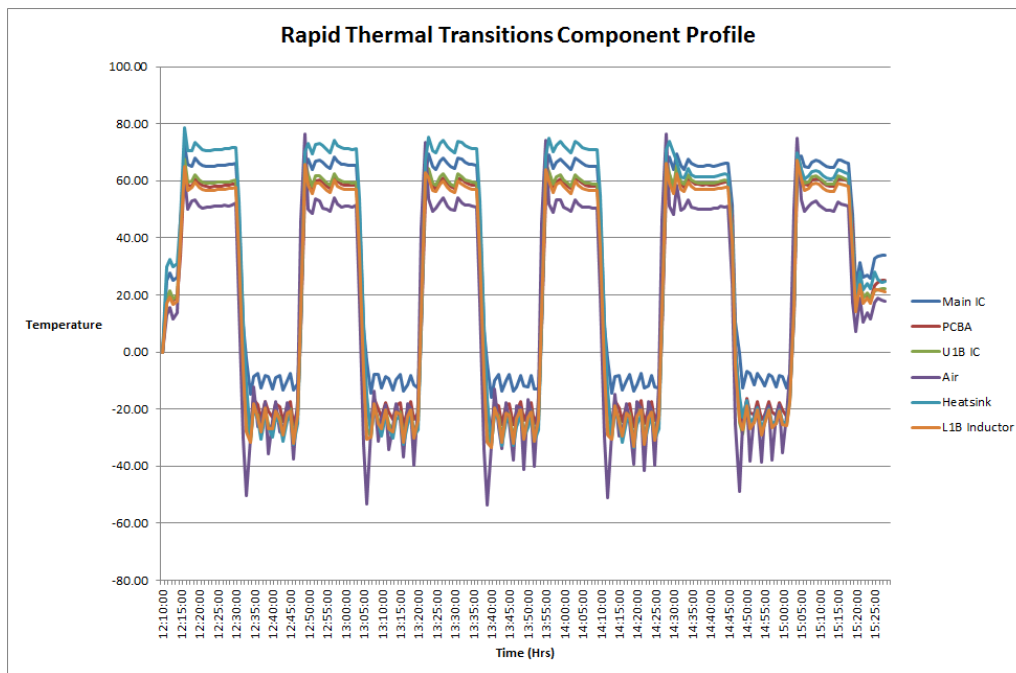


Figure 8: Rapid Temperature Transitions Component Profile

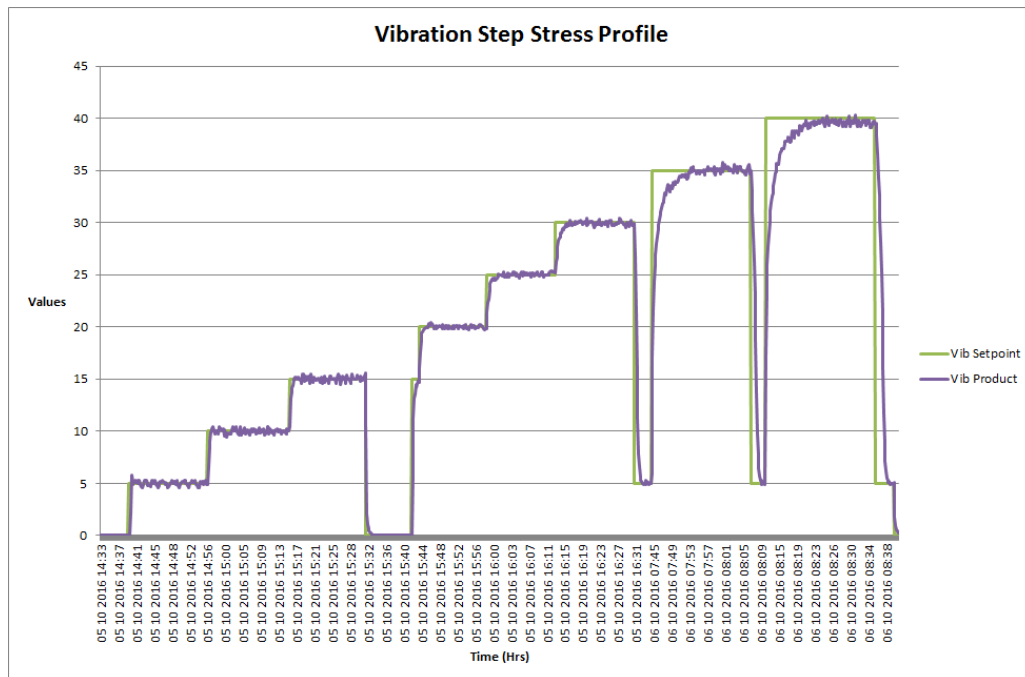


Figure 9: Vibration Step Stress Profile

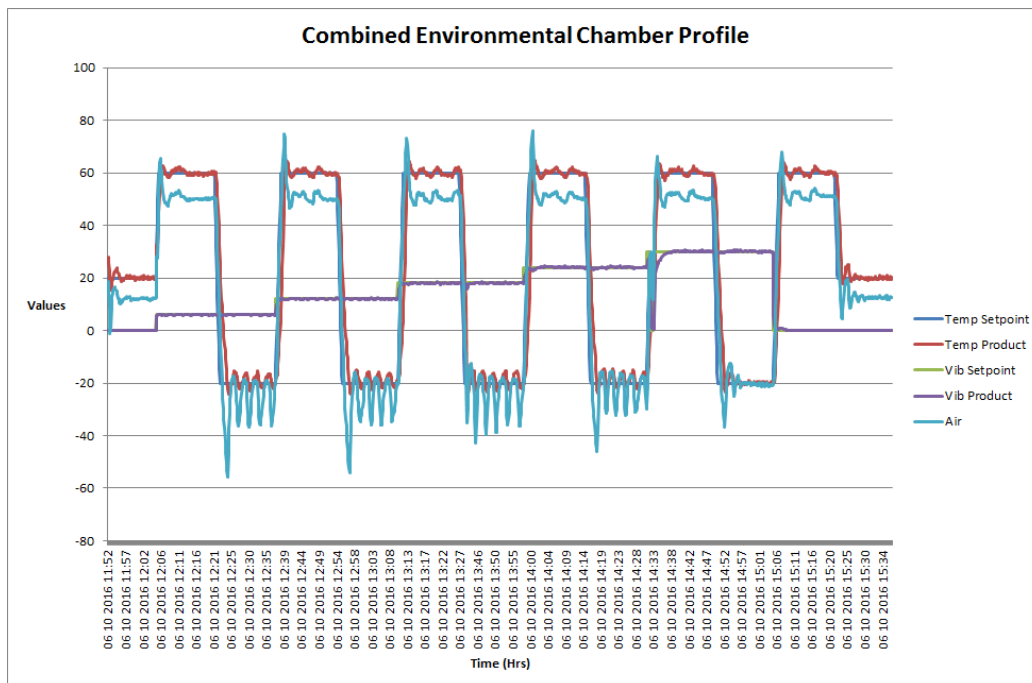


Figure 10: Combined Environmental Profile

11.0 Test Setup Images

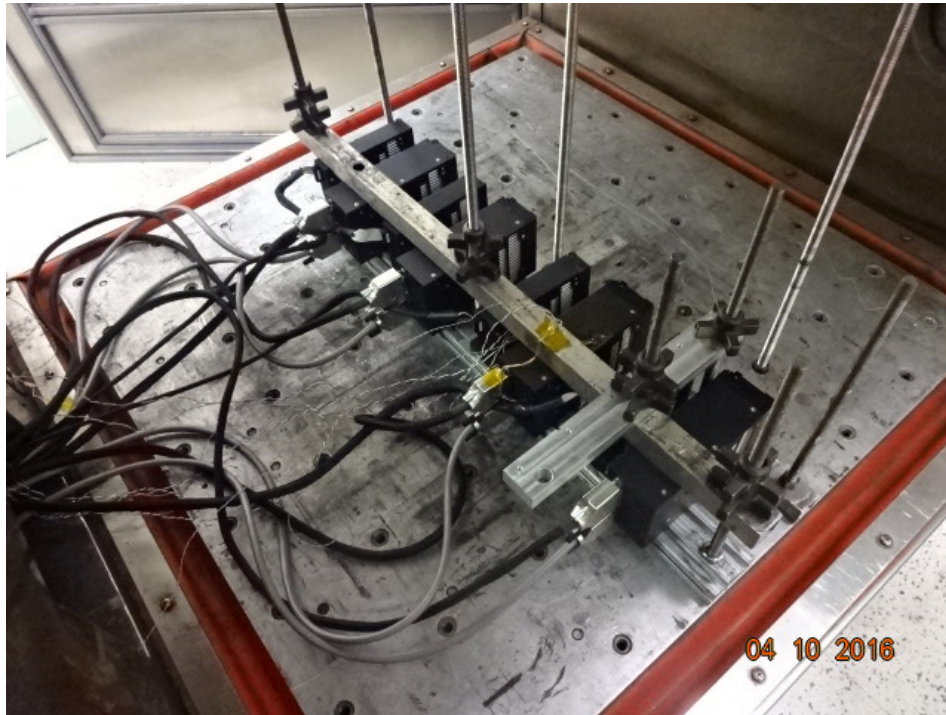


Figure 11: Thermal Setup

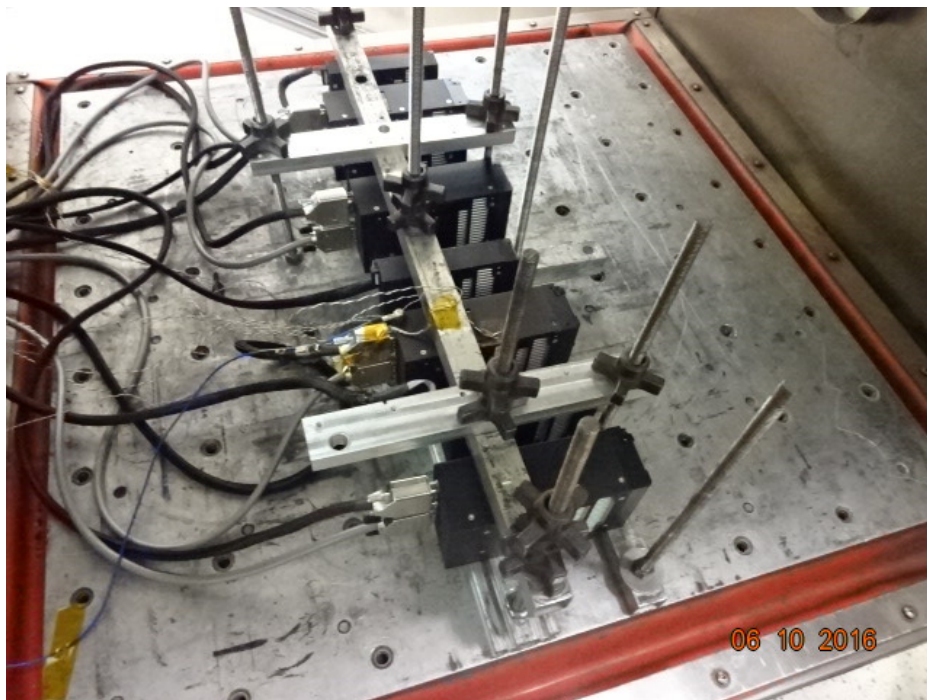


Figure 12: Vibration Setup

11.1 Thermocouple Setup

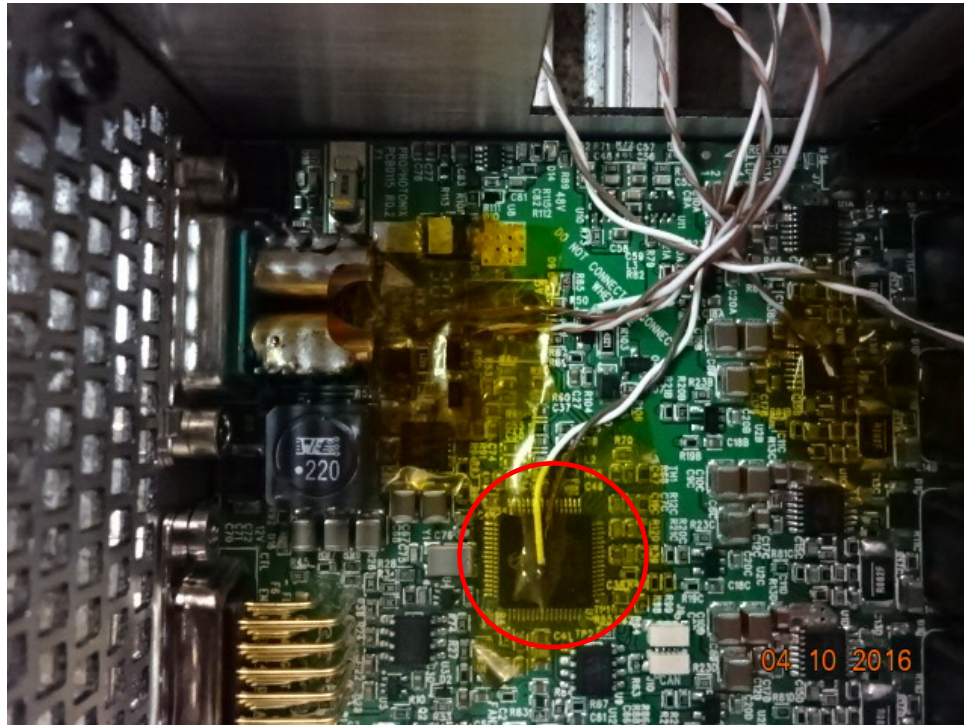


Figure 13: Main IC thermocouple location



Figure 14: PCBA thermocouple location

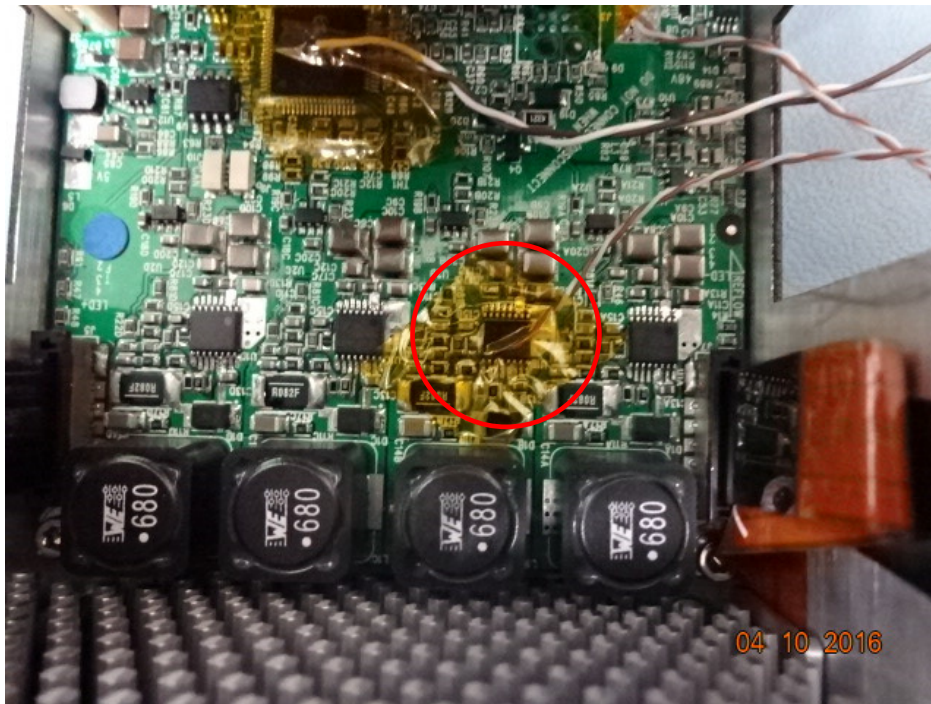


Figure 15: U1B IC thermocouple location



Figure 16: Air thermocouple location

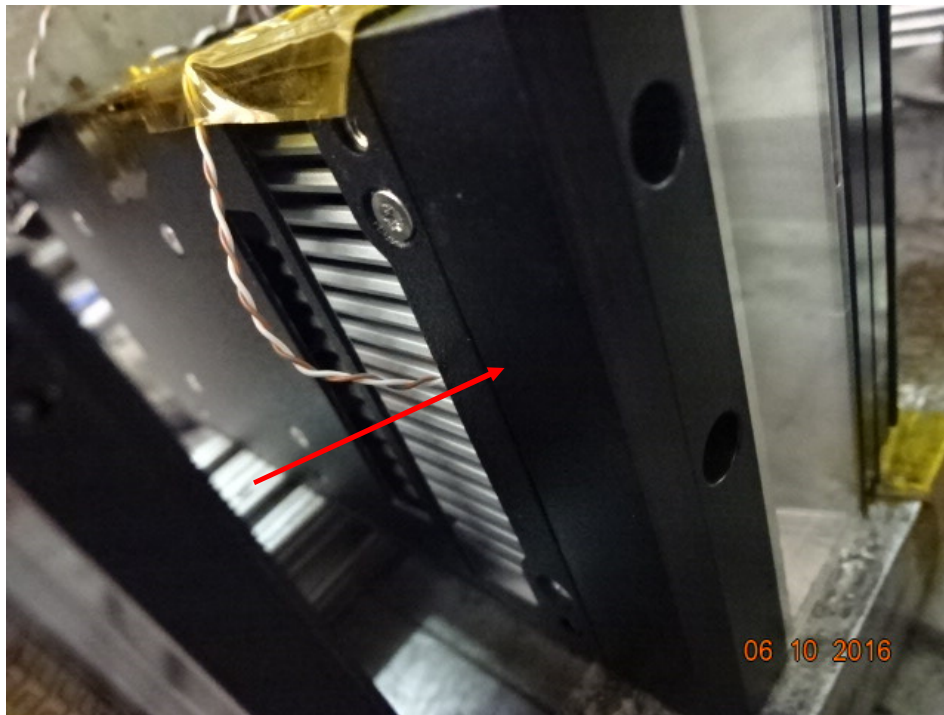


Figure 17: Heatsink thermocouple location

11.1 Accelerometer Setup

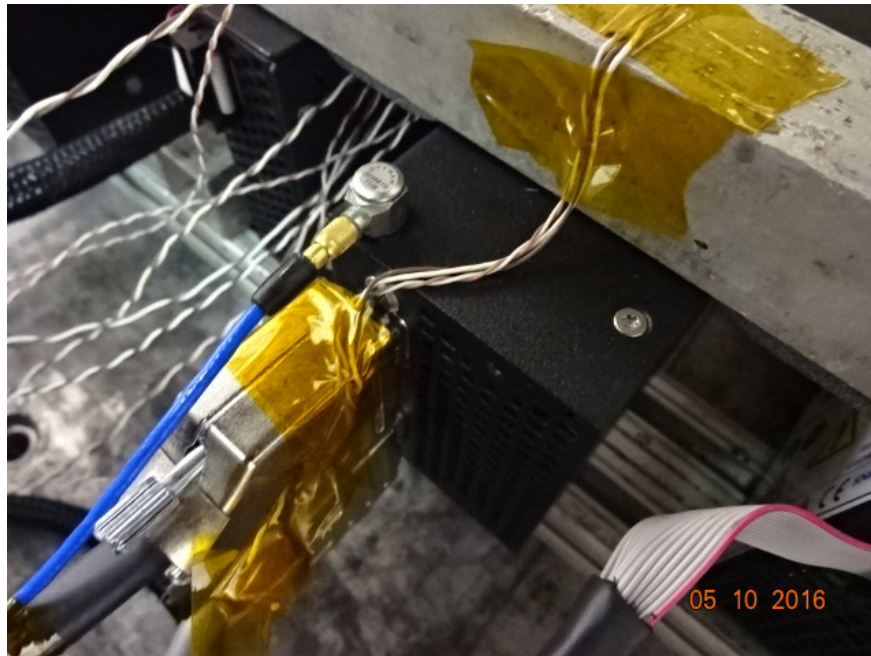


Figure 18: CH 1 Top (Z) of test fixture mounting in halt chamber

12.0 Test Result Images



Figure 19: Cover Damage on unit following vibration testing

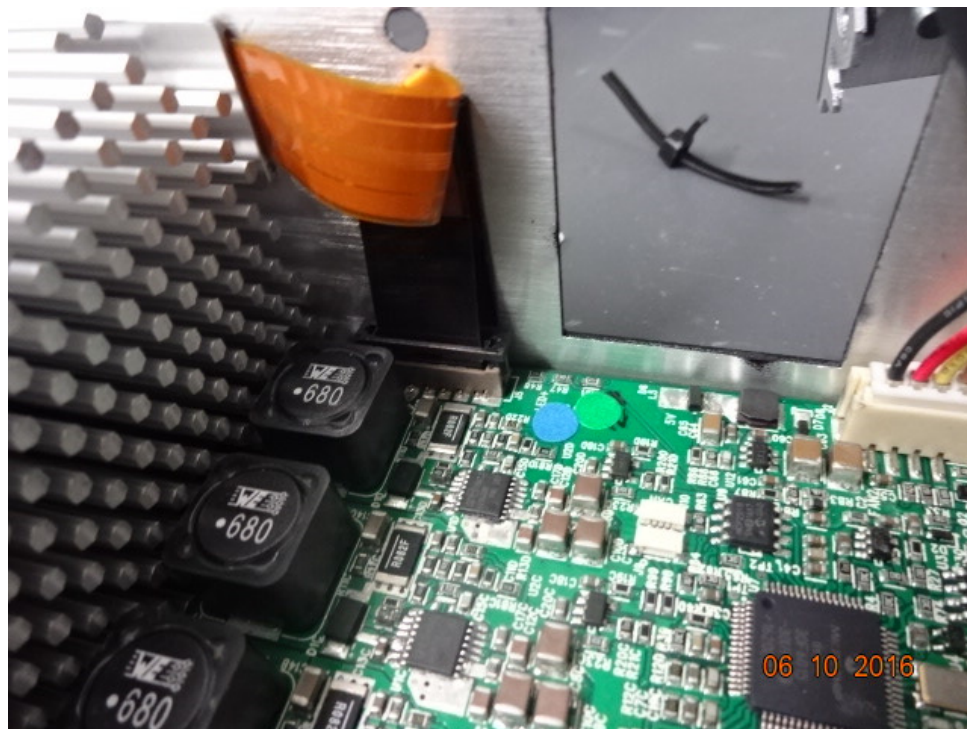


Figure 20: Flexi cable that became loose during vibration testing and failed at 40G