sensonor Sensonor AS	# TECHNICAL NOTE		
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Document Title Radiation testing of STIM210 and STIM300			

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Abbreviations

COTS	Commercial Off-The-Shelf
CRC	Cycle Redundancy Check
ESD	Electro-Static Discharge
IMU	Inertial Measurement Unit
LEO	Low Earth Orbit
LP filter	Low-Pass filter
MEMS	Micro-Electro-Mechanical System
PIF	Proton Irradiation Facility
PMMA	Polymethyl methacrylate
PSI	Paul Scherrer Institut
PSU	Power Supply Unit
RISC ARM	Reduced Instruction Set Computer / Advanced RISC Machine
SAA	South Atlantic Anomaly
SEE	Single Event Effect
SEFI	Single Event Functional Interrupt
SEL	Single Event Latch-Up
SMU	Source Measure Unit
TA	Technology Acceptance
TID	Total Ionizing Dose
UUT	Unit Under Test

1 Summary

This document describes the test procedure and results of Technology Acceptance (TA), Total Ionizing Dose (TID) and Single Events Effects (SEE) tests on Sensonor STIM210 gyro and STIM300 IMU. The tests have been performed on a total of 42 devices, 2+2 (STIM210+STIM300) samples for TA test, 5+5 samples for SEE test, 12+12 samples for TID test and 2+2 references. After TA and radiation tests, the units have undergone a thorough analysis program with error correction and testing. The test results are compared to original measurements done prior to TA tests and irradiations.

Both STIM210 and STIM300 passed the TA test verifying that the products have a general robustness to function in Space.

The cross section related to SEE has been established for STIM210 and STIM300. In the simulated case of a 10 year mission in heliosynchronous orbit at 800 km with 11.1mm aluminum shielding, several 10s of events must be expected.

Further results from the test campaign indicate that the gyros in STIM210 and STIM300 survives a TID level up 5kRad when powered up and up to 7 kRad when unpowered. These radiation levels are considered within acceptable range for many LEO operations.

The accelerometers and inclinometers shows a degradion when exposed to radiation.

Acknowledgements: Sensonor wishes to extend its gratitude to Norwegian Space Center for their financial contribution and to Dr. Michael Steffens at the Fraunhofer Institute INT in Euskirchen, Germany, for invaluable support in defining, preparing and conducting the testing at the two radiation facilities and writing of the report from the test campaign.

2 Introduction

STIM210 and STIM300 are MEMS based gyro systems and IMUs that are frequently used in various space applications e.g. in LEO satellite systems. The STIM210 and STIM300 are not designed to be radiation-hardened devices. Given their extended use in space, there has been a desire to test their resilience towards various types of radiation at selected radiation levels.

3 Objective

The objective is to document the results from the radiation testing on STIM210 and STIM300 and the following failure analyses.

4 Test plan

The test plan consists of 3 individual set of tests, as shown in Figure 1.

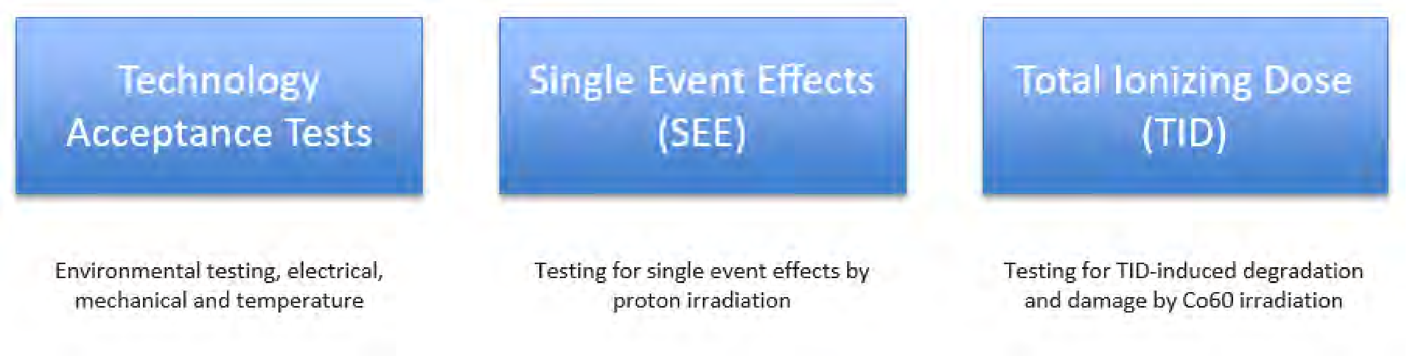
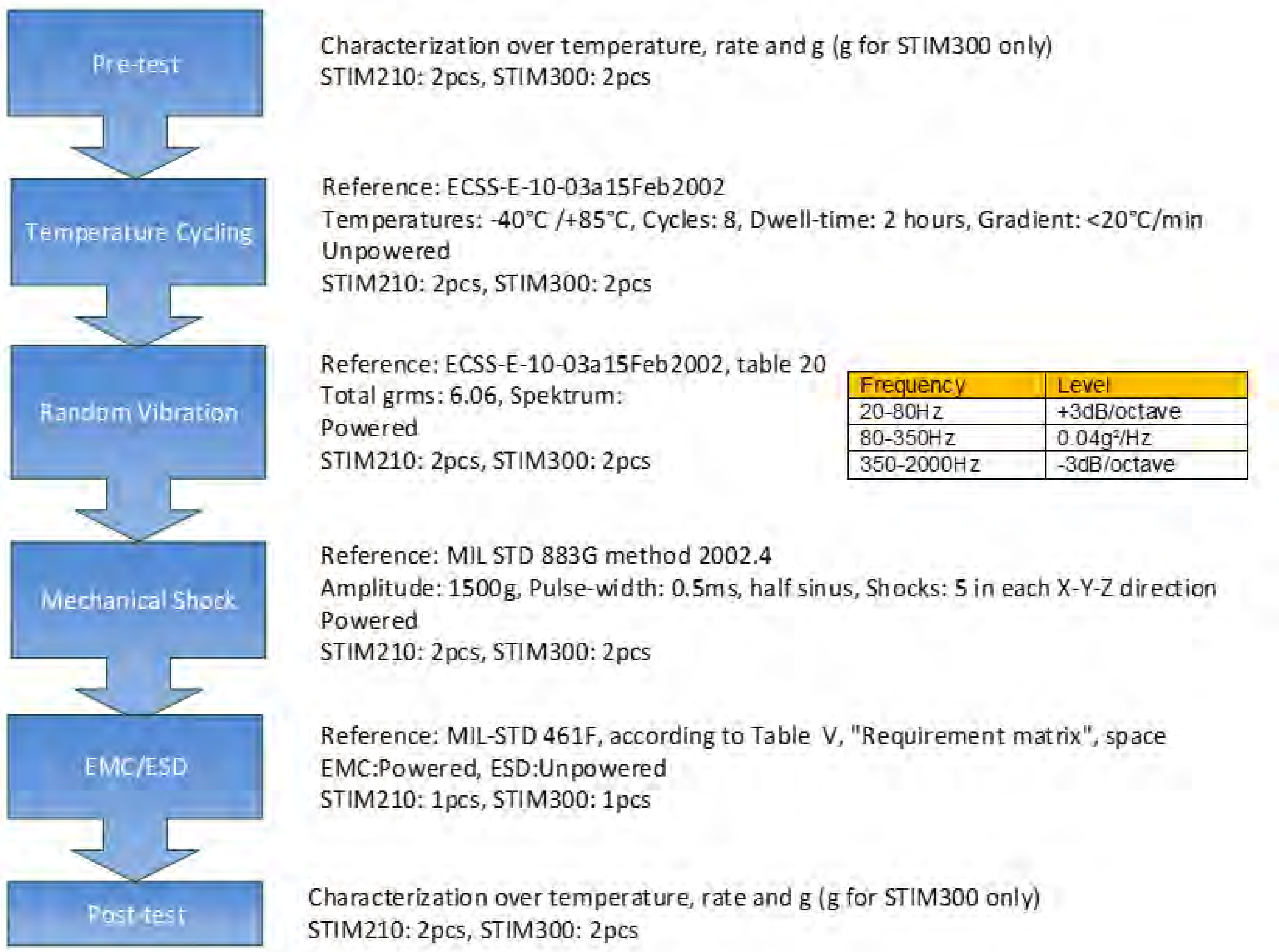


Figure 1: Overview of tests

Prior to and after the TA and the radiation tests, all UUTs were tested at Sensonor in a selected set of production test insertions. These Pre- and Post-tests are full product characterization tests done at various temperature levels, temperature gradients, rate and acceleration levels. Results from these tests are used for comparison of performance before and after the set of tests in Figure 1.

4.1 Technology Acceptance test plan

Figure 2 shows the test flow for the TA test.



Frequency	Level
20-80Hz	+3dB/octave
80-350Hz	0.04g²/Hz
350-2000Hz	-3dB/octave

Figure 2 Test plan for the Technological Acceptance test

A summary of the EMC/ESD susceptibility sub-test is given in Table 1. Some results are part of a generic qualification program at Sensonor, and is denoted as “Generic results” in the table.

Table 1: Summary, EMC/ESD sub-test

Test type	Standard	Condition	Comment
Conducted emissions	MIL-STD-461F, CE102	10kHz-10MHz	Generic results
Conducted susceptibility, bulk cable injection	MIL-STD-461G, CS114	0.01-200MHz, limit: curve 4 (3)	To be performed
Immunity to bulk current impulse excitation	MIL-STD-461F, CS115	Pulse:30ns, 30pps in 60sec	Generic results
Immunity to damped sinusoidal transients	MIL-STD-461F, CS116	0.01-100MHz	Generic results
Radiated emissions, electric field	MIL-STD-461G, RE102	10kHz-2GHz	To be performed
Radiated susceptibility, electric field	MIL-STD-461F, RS103	2MHZ-18GHz	Generic results
ESD: Immunity to electrostatic discharges	RTCA DO160E, section 25	15kV	Generic results

4.2 SEE test plan

4.2.1 Estimation of proton induced TID

The information given by PSI included a simple approximation of the TID in a bare silicon die exposed to the beam. This approximation does not take the package of the UUTs into account and thus does not represent the actual TID values in the UUT. An approximation reflecting the UUTs is given in this chapter.

To estimate the TID deposited by protons in the UUT, Monte Carlo simulations were performed before the test campaign with the software FastRad (version 3.8).
A step file of the UUT enclosure was provided by Sensonor to Fraunhofer INT. The inner layout of the UUT was not provided and approximated by 5 layers of Silicon on FR4 printed circuit board material (Figure 3).
The thickness of a copper degrader in the beam line was varied leading to an energy degradation of the protons. Initial energies used were 200 MeV and 74 MeV as was initially planned, but only 200 MeV protons were used in the actual test campaign.
As the proton energy wasn't set directly, and as the actual degrader properties to achieve a certain proton energy were not provided by PSI, a series of simulations were performed (Figure 4). Per simulation run, 5E6 protons were simulated and the resulting flux and total dose scaled to an incident fluence of 1E11 p/cm^2.
In these simulations the TID deposition for energies below 100 MeV get quite significant, reaching up to 40 – 70 krad(Si) around 25 MeV (lower energies were not simulated).
Above 100 MeV, the dose deposition is nearly constant and below the TID limits found in the later TID campaign.
In addition, at 25 MeV the protons are already stopped in the enclosure or the Si/FR4 layers, thus the fluence reaching the bottom Silicon layer (labeled Si_1 in the figures) is reduced by approx. 60%.

While the inner layout of the UUTs is not fully reflected by these simulations, a few conclusions can be drawn:

- the total dose deposition above a proton energy of 100 MeV is nearly constant and might have no big influence on the effects
- At energies above 30 MeV, nearly all protons pass all the layers in the simulation. Below 30 MeV they are partially stopped. Thus at 30 MeV and 20 MeV SEE in lower-lying layers of the UUT should be less likely due to the reduction of particle flux.

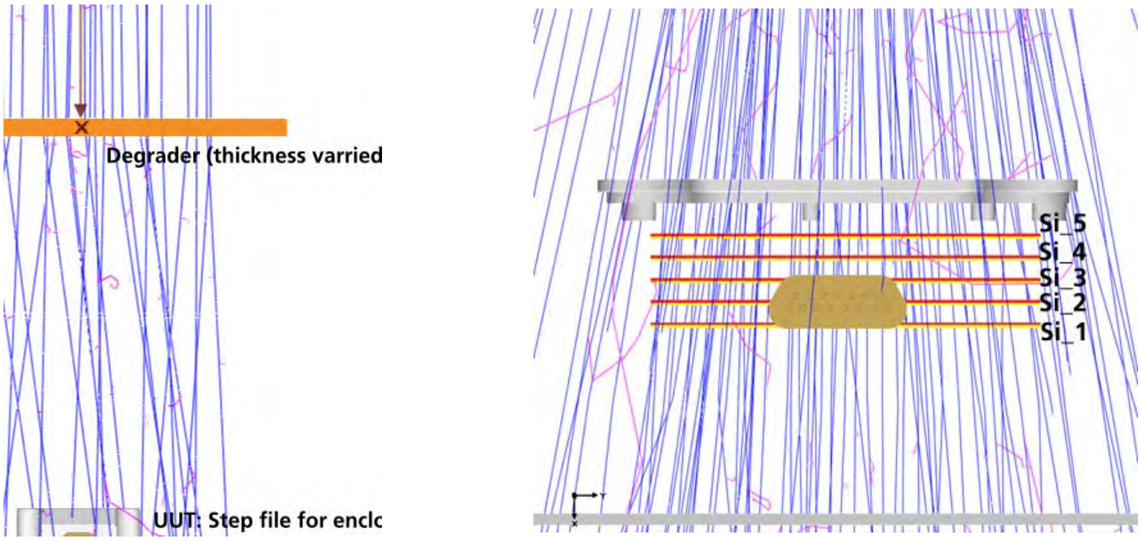


Figure 3: Sketch of simulated setup

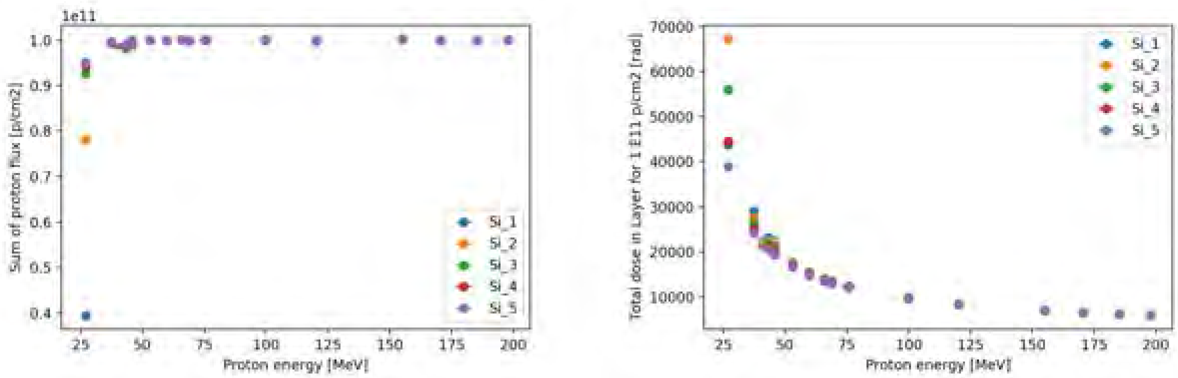
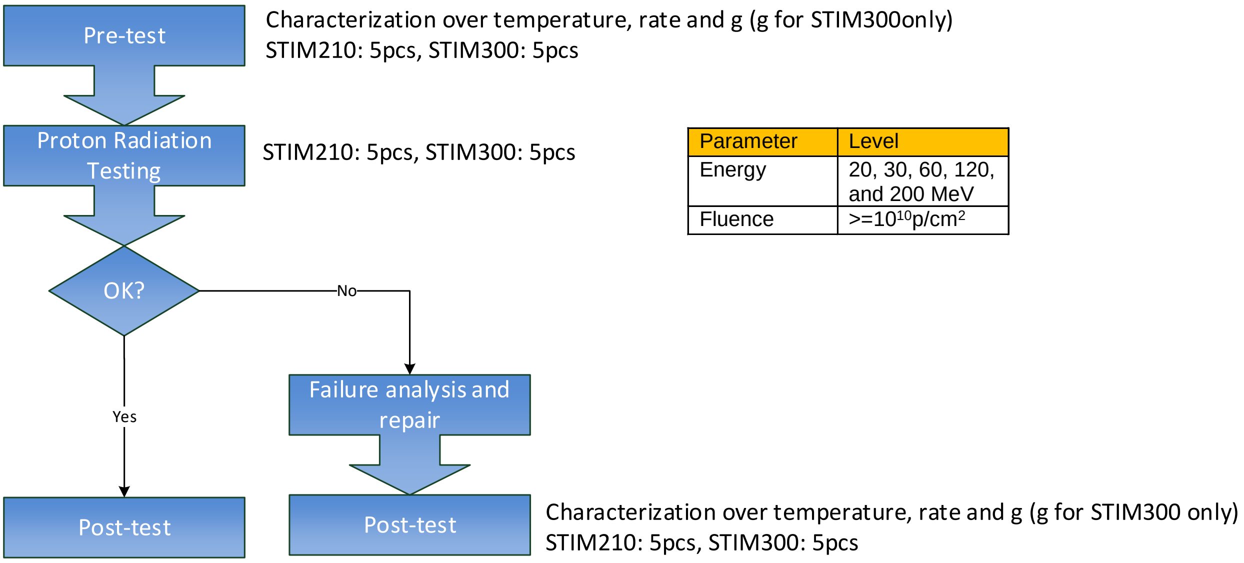


Figure 4: Simulation results (Si1 = bottom layer, Si5 = top layer). Left side: Simulated proton flux through the Si layers versus proton energy, Right side: Total dose deposited by the protons in the Si layers versus proton energy. The proton energies were evaluated after passing the degraders and before entering the UUT enclosure.

4.2.2 Original test plan



Parameter	Level
Energy	20, 30, 60, 120, and 200 MeV
Fluence	>=10^{10}p/cm^2

Figure 5 Pre-radiation test, SEE

5 UUTs per type will be exposed to a fluence of above 1E10 p/cm^2 at proton energies of 20, 30, 60, 120 and 200 MeV. All UUT's will be powered up during SEE test. The test logic is shown in Figure 6.

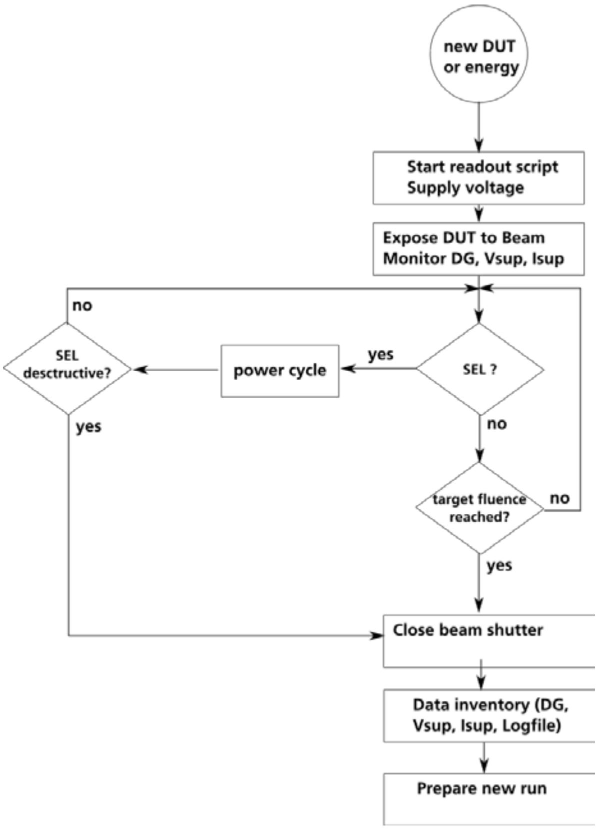


Figure 6: SEE: Test logic of the SEE radiation test

4.2.3 Test plan, revised

It was initially planned to perform tests at 20, 30 and 60 MeV proton energy by a reduction of an initial energy of 74 MeV. Each switch of the initial energy would have taken up to 2 hours of beam time, so a decision was made to use 200 MeV initial energy protons and degrade radiation by the PIF Energy Degrader (Figure 20).

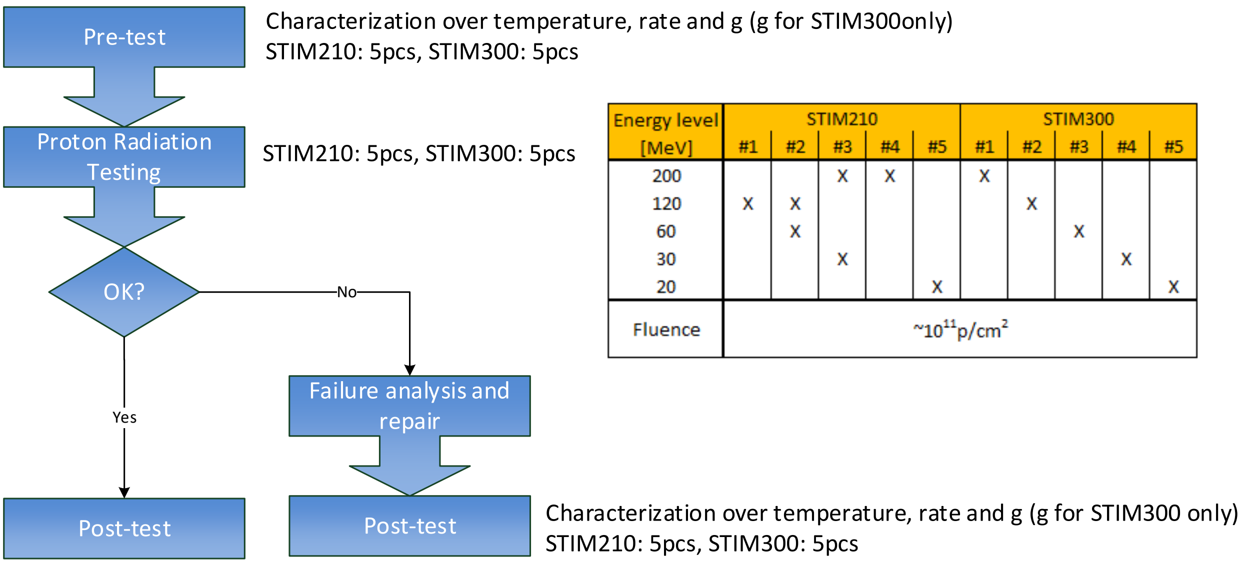
Calibration of the degrader to the final proton energies was performed by the PIF staff before the shifts. During the experiments the user can set the beam energy to these predefined values by controlling the PIF copper degrader. Furthermore the beam can be halted by the user from the control room.

However, to have some statistics of single event latch-ups, a fluence of 1E11 p/cm^2 was preferable and thus targeted.

Several issues encountered on-site led to changes in the test plan:

- Permanent failures, e.g. loss of communication, of the UUTs were encountered and thus no further tests with that UUT could be performed.
- The proton flux of approx. 1E8-2E8 p/cm^2/s that was communicated beforehand was only applicable to the highest proton energy of 200 MeV. At the lowest energies the achievable flux was approx. a factor of 5 smaller. Due to a large number of current increases in some runs, the flux had to be further decreased.
- Some runs, especially at low energies, were interrupted due to power failures of the test laptop positioned in the irradiation room. Without the beam on, the laptop was running stable and without any issues, e.g. over the time between shifts.

Due to these circumstances, a new test plan was created. The revised test plan is seen in Figure 7.

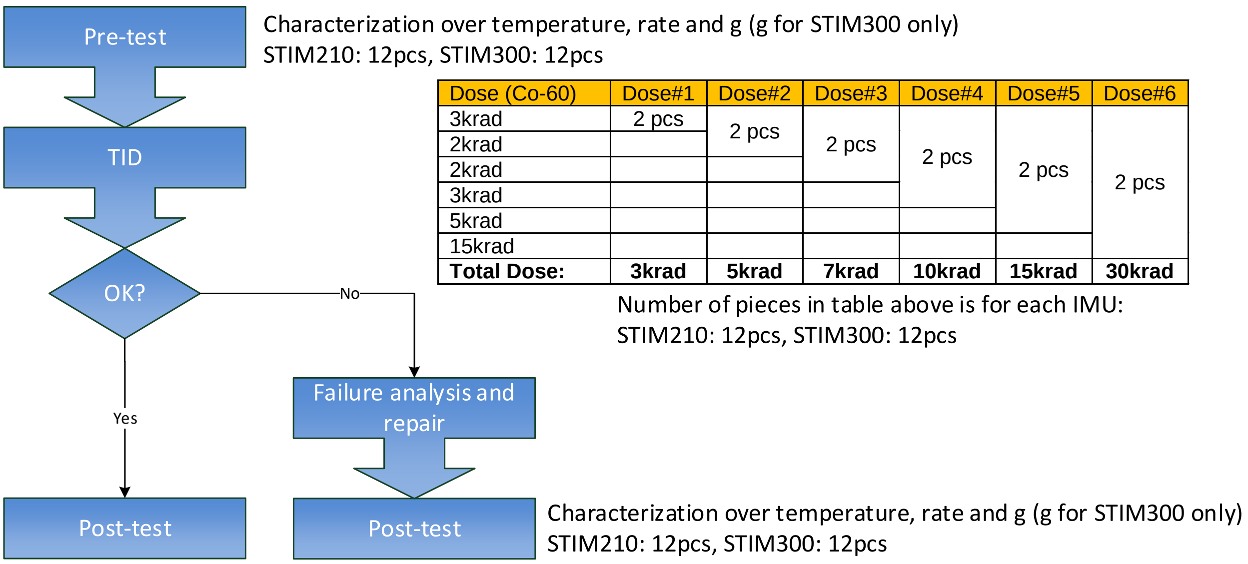


Energy level [MeV]	STIM210 #1	STIM210 #2	STIM210 #3	STIM210 #4	STIM210 #5	STIM300 #1	STIM300 #2	STIM300 #3	STIM300 #4	STIM300 #5
200			X	X		X				
120	X	X					X			
60		X						X		
30			X						X	
20					X					X
Fluence	~10^{11}p/cm^2									

Figure 7 Revised Test plan, SEE test

4.3 TID test plan

The test plan for TID testing is shown in Figure 8.



Dose (Co-60)	Dose#1	Dose#2	Dose#3	Dose#4	Dose#5	Dose#6
3krad	2 pcs	2 pcs	2 pcs	2 pcs	2 pcs	2 pcs
2krad						
2krad						
3krad						
5krad						
15krad						
Total Dose:	**3krad**	**5krad**	**7krad**	**10krad**	**15krad**	**30krad**

Figure 8 Test plan, TID test

Starting with 6 powered and 6 unpowered UUTs, one UUT of each power condition is to be removed after completion of a dose step for further post-test analysis. This is valid for both STIM210 and STIM300
The removal of the UUTs follows a pre-defined pattern (described in Figure 9) irrespective of the outcome of the individual post-irradiation test results. A pre-irradiation diagnostic read-out is to be performed on all UUTs.

#	Dose step	STIM210 and STIM300 test logic											
		Powered						Unpowered					
		#1	#2	#3	#4	#5	#6	#1	#2	#3	#4	#5	#6
0	Pre-irradiation	■	■	■	■	■	■	■	■	■	■	■	■
1	0 -> 3 krad	■	■	■	■	■	■	■	■	■	■	■	■
2	3 -> 5 krad		■	■	■	■	■		■	■	■	■	■
3	5 -> 7 krad			■	■	■	■			■	■	■	■
4	7 -> 10 krad				■	■	■				■	■	■
5	10 -> 15 krad					■	■					■	■
6	15 -> 30 krad						■						■

□	Not included at dose step
■	Irradiated

Figure 9: TID Test logic

5 Test samples

STIM210 is a cluster of one, two or three high accuracy MEMS-based gyros and STIM300 is an IMU consisting of three high accuracy MEMS-based gyros, 3 high stability accelerometers and 3 high stability inclinometers, built into a small package. Each sensor cluster is factory-calibrated for bias, sensitivity and compensated for temperature effects to provide high accuracy measurements in the temperature range -40 °C to +85 °C. The unit runs off a single 5 V supply. See Figure 10 and Figure 11. Note that the block diagram in Figure 10 is for STIM300 only.

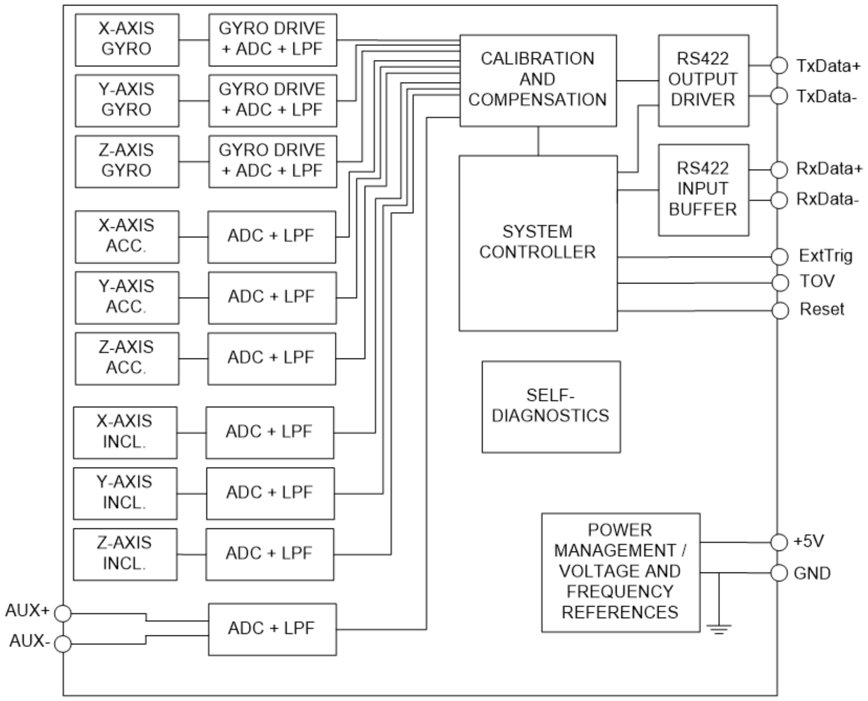


Figure 10: STIM300 Functional block diagram

Figure 11: STIM210 Gyro module and STIM300 IMU

5.1 Sample selection

Sample selection was done according to Table 2

Table 2: Samples used in test

TEST	STIM210			STIM300			Powered
	ID	Rev.	Test position	ID	Rev.	Test position	
Technology Acceptance Test	N25581824753909	J	N/A	N25581817663510	G	N/A	Ref plan
	N25581824753919	J	N/A	N25581820707832	G	N/A	Ref plan
TID	N25581824756143	J	1	N25581817664570	G	9	Y
	N25581824756160	J	2	N25581820707845	G	10	Y
	N25581824756157	J	3	N25581817663459	G	11	Y
	N25581824756150	J	4	N25581820707843	G	12	Y
	N25581824756162	J	5	N25581818673709	G	1	Y
	N25581824756166	J	6	N25581820706758	G	2	Y
	N25581824756175	J	7	N25581804458810	G	3	N
	N25581824756158	J	8	N25581817664560	G	4	N
	N25581824756169	J	9	N25581748366700	G	5	N
	N25581824756173	J	10	N25581748367781	G	6	N
	N25581824756168	J	11	N25581804458811	G	7	N
	N25581824756165	J	12	N25581820707844	G	8	N
SEE	N25581824756125	J	1	N25581820708894	G	1	Y
	N25581824756127	J	2	N25581817663472	G	2	Y
	N25581824756128	J	3	N25581820708868	G	3	Y
	N25581824756122	J	1	N25581804460923	G	1	Y
	N25581824756124	J	2	N25581814582336	G	2	Y
References	N25581824753898	J	N/A	N25581818673718	G	N/A	N
	N25581824753893	J	N/A	N25581817663476	G	N/A	N

For both STIM210 and STIM300, all modules are of the latest version and were tested and calibrated just prior to the start of the test program.

6 Technology Acceptance Test

This Section features the description of the TA tests with the facilities and equipment used for the tests. The results are shown in section 6.2.

6.1 Execution of test

6.1.1 Facilities

The test program has been performed at various facilities:

- Pre and post test — Sensonor, Norway
- Temperature cycling — Sensonor, Norway
- Vibration — Sensonor, Norway
- Mechanical shock — Kongsberg Norspace, Norway
- EMC — Force Technology, Denmark

The TA tests are mostly the same type of tests done in Sensonor's standard product qualification program.

6.2 Results

6.2.1 Diagnostic test during TA test

A diagnostic test and a simple table measurement were done between each test step to verify the UUT's was still functional and without any status byte errors. No errors were observed.

6.2.2 Post TA Verification

Bias offset and Scale Factor were measured in Sensonor's production line. The results from these tests have been compared to the results of identical measurements made before the TA testing. A summary can be found in Table 3:

Table 3: Results TA test

Product	Results		
	Gyro	Acc	Inc
STIM300	OK	OK	OK
STIM210	OK	N/A	N/A

The plots in Figure 12 to Figure 17 shows the absolute value of the bias and scale factor drift between pre- and post-tests. The boxplots represents the interquartile range with the middle line representing the median. The full comparison of test results can be found in Appendix B.

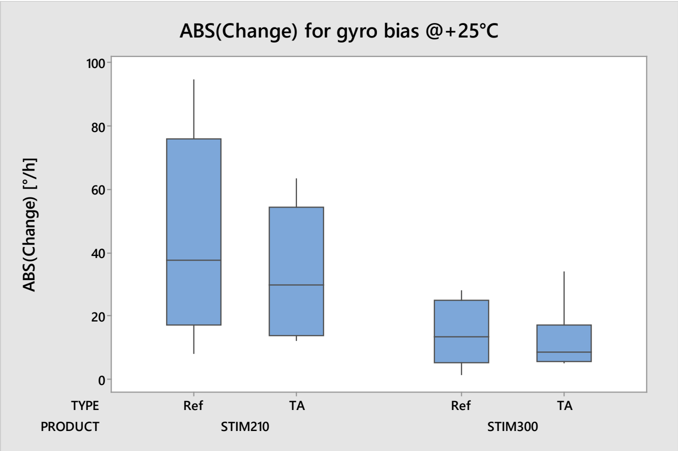


Figure 12 Change in gyro bias

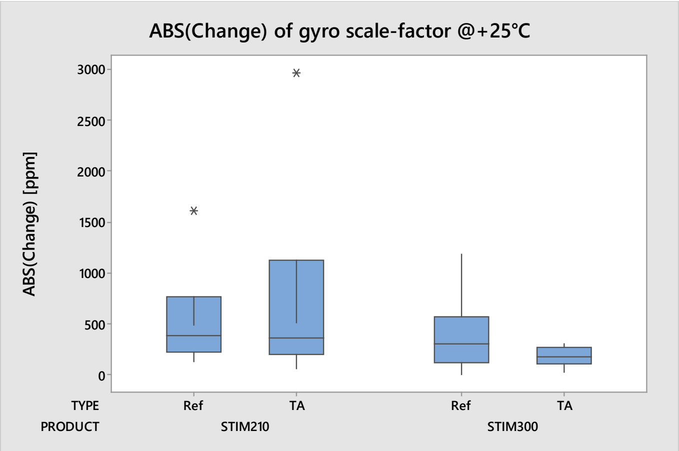


Figure 13 Change in gyro scale factor

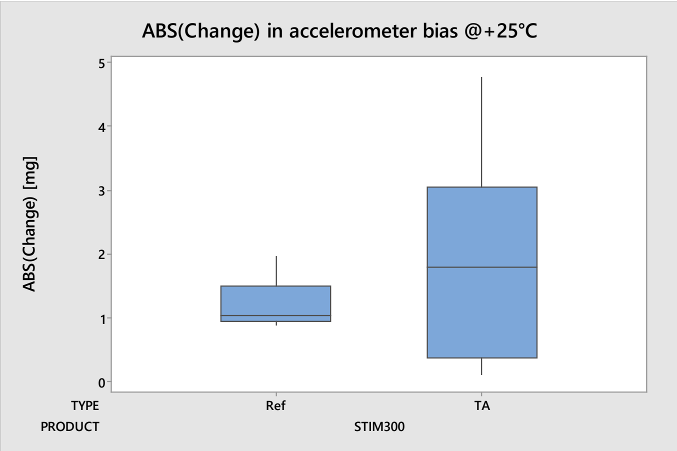


Figure 14 Change in accelerometer bias

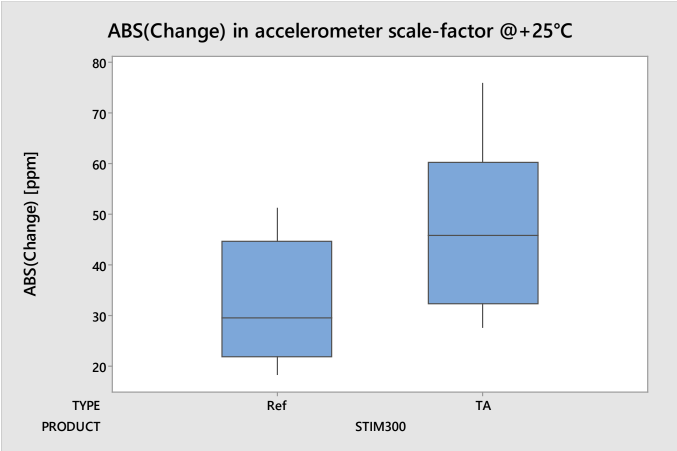


Figure 15 Change in accelerometer scale factor

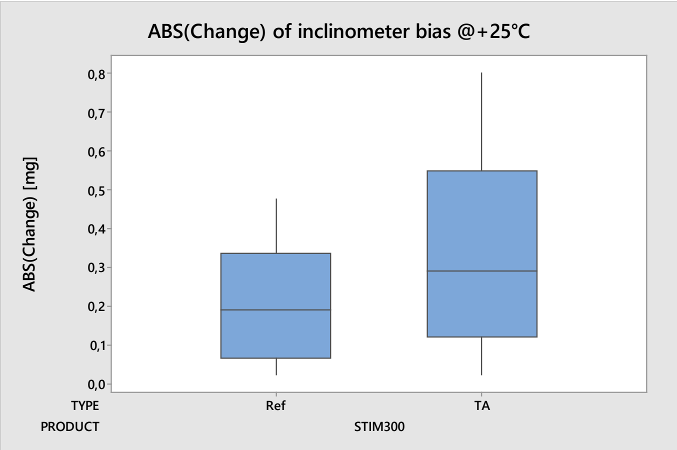


Figure 16 Change in inclinometer bias

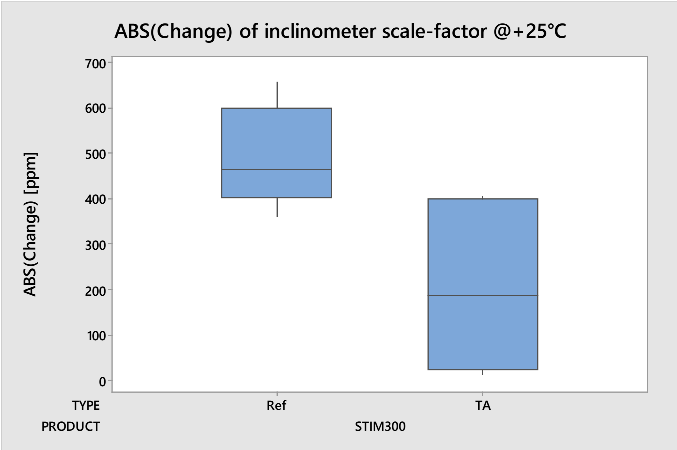


Figure 17 Change in inclinometer scale factor

The results from the EMC/ESD tests are summarized in Table 4. Refer to Appendix H and Appendix I for complete EMC test reports for STIM300 and STIM210 respectively.

Table 4: Summary of Results EMC/ESD tests

Test type	**STIM210**	**STIM300**
Conducted emissions	Pass	Pass
Conducted susceptibility, bulk cable injection	Pass	Pass
Immunity to bulk current impulse excitation	Pass	Pass
Immunity to damped sinusoidal transients	Pass	Pass
Radiated emissions, electric field	Pass	Pass
Radiated susceptibility, electric field	Pass	Pass
ESD: Immunity to electrostatic discharges	Pass	Pass

7 Single Event Effects Test

This Section features the description of the SEE tests using the irradiation facility (PIF) at Paul Scherrer Institut (PSI) and the equipment used for the tests. The results are shown in section 7.2.

7.1 Execution of test

7.1.1 Facility

SEE testing of the UUTs was performed at the PIF of the Laboratory for Particle Physics, Paul Scherrer Institut, Villigen, Switzerland.

The PIF proton beam is delivered from the COMET (PROSCAN) accelerator and the PIF experimental area is located in the PROSCAN accelerator Hall (Figure 18). The beam delivered to PIF can have primary energies in the range from 230 MeV down to 74 MeV. To avoid a long break of several hours to setup new beam parameters, a beam of 200 MeV initial energy was used for all tests.

The experimental set-up consists of the local PIF energy degrader, beam collimating and monitoring UUTs. A moveable XY table with sample holder and a laser mounted downstream from the XY tables allowed for controlling the positioning of the UUT (Figure 20 right). The beam energy delivered from PROSCAN was degraded locally using the PIF energy degrader (Figure 20 left). In that way the beam energies could be set from the PIF control room (Figure 19).

Figure 18: PIF, Exposure room

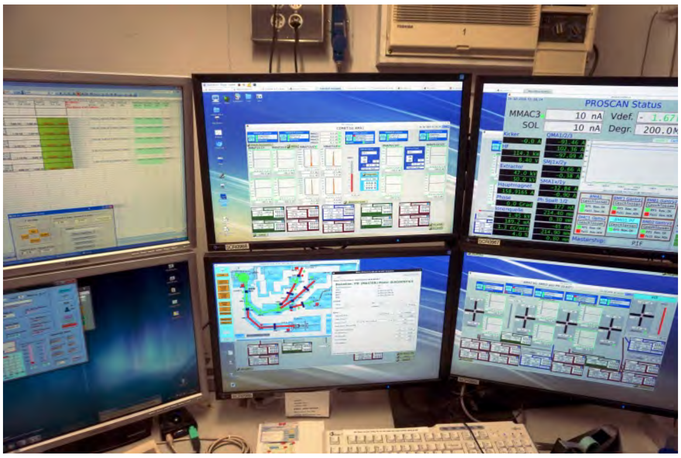


Figure 19: In PIF control room, Monitor and control screens

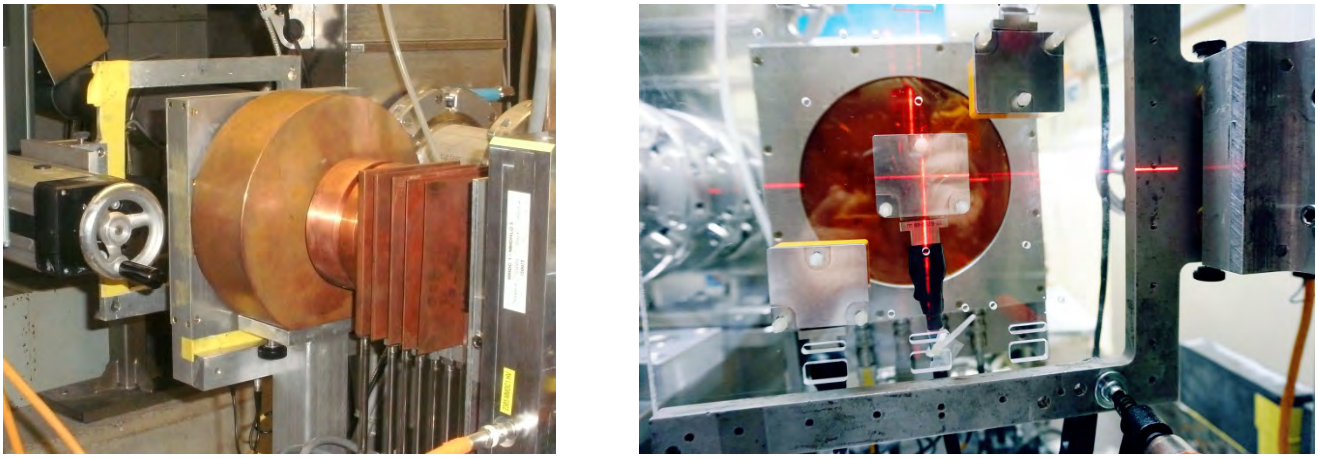


Figure 20: SEE Facility. Left: PIF Energy Degrader. Right: Laser-assisted alignment

7.1.2 Sample holder / Irradiation board

The custom-built irradiation and test board is shown in Figure 21 and Figure 22. The UUTs were attached to the board by plastic screws and nuts. The board allows the fixture of up to 5 evenly distributed UUTs. However, during the campaign only 3 UUTs were simultaneously installed on the fixture.

The beam calibration performed by the PIF staff assumed a distance of 10 cm from the energy degrader to the UUTs. That distance was thus set using the moveable table in the area.
To limit the area of exposure to the UUTs, a circular collimator of 5 cm diameter was installed. The beam profile measured and provided by the PIF staff is shown in Figure 23. In X-direction, the beam shows a flat profile over the UUT dimension, on the y-axis there is some reduction of the intensity. Overall, the profile looks reasonable. The UUT positions on the board were determined using a laser system installed in the irradiation room (Figure 20). To place a UUT in the center of the beam, the board was moved remotely to these positions.

Figure 21:SEE: Irradiation board installed at PIF, PSI

Figure 22: SEE: Irradiation board

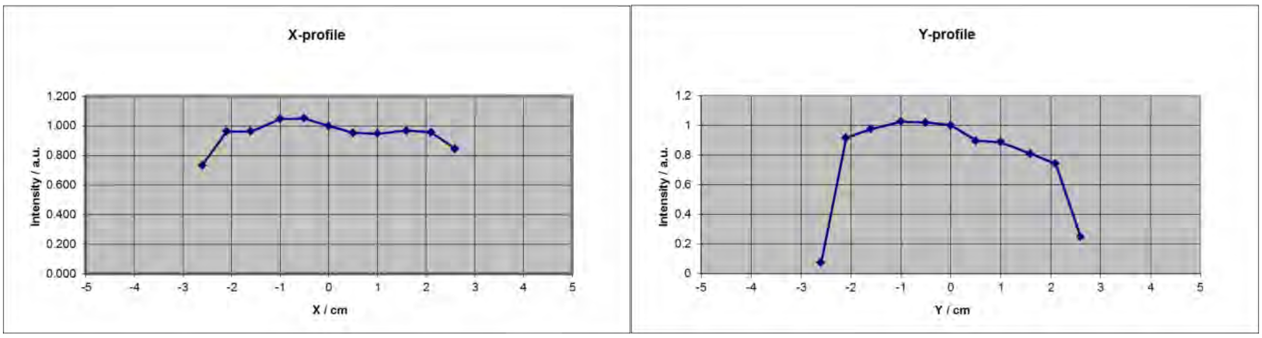


Figure 23: PIF: Beam profile measurement provided by PIF

7.1.3 Power conditioning and test setup

During the irradiation the samples were biased according to the circuit-description of the irradiation test plan.

The cables used to bias and readout the UUTs were provided by Sensonor for the conduction of the tests. The cables were uniquely labelled at both ends to prevent mix up of the cables. To compensate for the voltage drop over the cable the UUTs were powered with 5.2 V from the PSU.

A Rohde & Schwarz HMP4030 power supply (Eq.Id E-PS3-006) was used for biasing during the STIM210 and STIM300 tests. The supply was not calibrated but the voltage and current were checked with a calibrated Keysight 34401A digital multimeter (Eq-Id.: E-DMM-015, calibration due 05/2019) at Fraunhofer INT before shipping the supply to PSI. As the main purpose of the test was the detection of single event latch-up which show as sudden increase of the current to the compliance maximum, absolute accuracy of the readings was not a requirement. With this power supply, 3 UUTs can be simultaneously connected with only the UUT currently in the beam being powered.
Power cycling of the supply on observation of a latch-up or similar abrupt current increases had to be done manually. A new data file was started after each power cycle.

The power supply was connected to a test laptop via USB with test software written in LabView controlling and reading the supply. The supply and that laptop were inside the irradiation room all the time. The test laptop was connected via a connector panel installed at the facility to another laptop in the PIF control room, from where it was operated via remote desktop. At several instances the test laptop in the irradiation room crashed leading to several interruptions of runs and in one instance to the loss of data (Run #27). Also the crashes happened at proton energies of 60 MeV or lower, so a potential reason might be that the laptop was exposed to secondary particles, e.g. neutrons, generated in the degrader while the beam was running at these energies, inducing failures in the laptop.

Table 5: TID: Biasing and test equipment

Equipment	Manufacturer	Model	Eq-ID	Calibration due
Power supply	Rohde & Schwarz	HMP4030	E-PS3-006	n/a

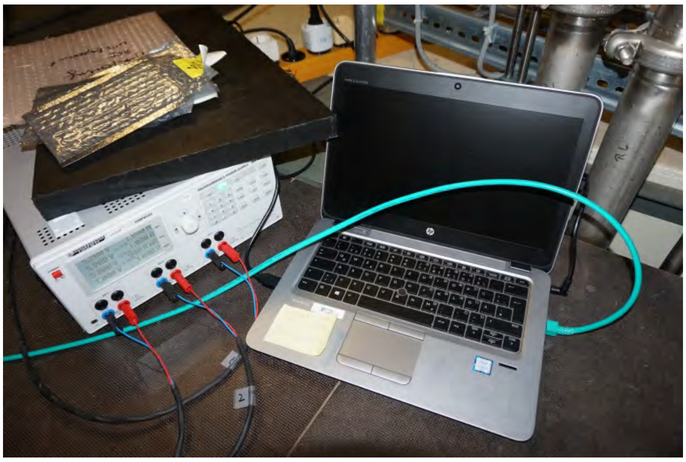


Figure 24: SEE: Biasing and test equipment.

The data readout of the UUTs ran continuously during the proton irradiations. It was chosen to use a regular PSU for powering the UUTs, as an SMU might not have coped with the UUT in-rush current, the limitation to 3 UUTs and the necessity to perform manual power cycling operations during the irradiation.

7.1.4 Environmental variables

Irradiations were performed at room temperature and normal conditions (humidity, pressure) in ambient light. Values of the environmental parameters in the radiation room are not available.

7.1.5 Measurement parameters

The supply current and voltage were continuously measured by the electrical setup by INT. Plots of the supply current and voltage are included in Appendix G. Datagrams of the UUT output were continuously recorded during the runs.

Table 6: Measurement parameters (continuous during irradiation)

No.	Characteristics	Symbol	Test Conditions
1	Supply current of UUT in beam	I_{supp}	V_{DD} = 5.2 V, I_{max} set to 1 A
2	Supply voltage of UUT	V_{supp}	V_{DD} = 5.2 V

7.1.6 Measurement procedures

Online measurements of the supply currents were programmed, controlled and stored using software written by Fraunhofer INT in LabView. Data points were taken each 1.5 seconds (limited by the supply).
In some runs, more likely when using lower energetic protons, the test laptop shut down unexpectedly and immediately. In two instances there was a noticeable freezing before the crash, but in most cases the laptop crashed without proper termination of LabView or Windows leading to a loss of all data since the last power cycle.
When observing a proton-induced latch-up, an abrupt increase of current accompanied by a drop in supply voltage, the power supply was power-cycled manually. In many instances, the increase in current did not go to the maximum limit programmed in the supply and is thus most likely not a latch-up but some sort of high current state. In some of these cases it was decided not to perform a power cycle to observe the following UUT behaviour.

No apparent failures due to TID, e.g. continuous unrecoverable degradation, deposited by the protons were encountered during the campaign. However as the TID test was only performed after the SEE tests, failure modes such as the abrupt increase of current were attributed to single events but also showed as failure modes in the later TID tests (ref. Appendix A).

7.2 Results

7.2.1 Irradiation steps

An overview of the runs is shown in Table 7 below. More information is given in Appendix F.

Due to the previously mentioned issues, the tests of some UUTs are spread across several runs. An overview per UUT is shown in Table 8.

Table 7: SEE:-Log file (Excerpt): Flux, Total fluence, # of power cycles and comments (identical to Table 22 in appendix G)

Run #	UUT	UUT	Proton energy [MeV]	Total fluence [cm-2]	Flux [cm-2 s-1]	power cycles	Comment
6	STIM300	1	120	1.00E+11	1.32E+08	2	
7	STIM300	2	120	1.32E+10	1.30E+08	2	Interrupted due to early errors
8	STIM300	2	120	8.05E+09	1.28E+08	0	Interrupted due to early errors
9	STIM300	2	60	9.49E+10	7.73E+07	20	Due to a power shutdown at the test laptop, premature end of power supply data
10	STIM300	3	30	6.47E+10	4.32E+07	1	Premature end of power supply data due to a power shutdown at the test laptop
11	STIM300	3	30	3.53E+10	4.32E+07	0	Continuation of run #10
12	STIM300	4	200	1.77E+10	6.23E+07	12	High number of current increases → prepare new run at reduced flux
13	STIM300	4	200	1.13E+10	1.74E+07	22	Continuation of run #12 at reduced flux. Current increases getting more frequent with time. Interruption to run diagnostics. Errors in diagnostics → no further tests with UUT
14	STIM300	3	200	1.55E+10	1.71E+07	18	Interruption to run diagnostics on UUT, Reference voltage failing → no further tests with UUT
15	STIM300	5	20	9.57E+10	3.26E+07	2	Beam offline for approx. 2 min
16	STIM300	5	20	4.99E+09	3.22E+07	0	Premature end of power supply data due to a power shutdown at the test laptop
17	STIM210	1	200	6.22E+09	1.81E+07	11	Interruption to run diagnostics on UUT
18	STIM210	1	200	2.15E+10	1.72E+07	46	continuation of run #17
19	STIM210	2	120	3.70E+10	6.55E+07	19	Interruption to run diagnostics on UUT
20	STIM210	2	120	6.30E+10	6.75E+07	11	continuation of run #19
21	STIM210	3	60	4.36E+10	7.84E+07	8	Run ended due to a power shutdown at the test laptop. While at other instances this was abrupt, here the laptop froze before crashing, allowing to shut down the beam before loss of data.
22	STIM210	3	60	5.63E+10	7.86E+07	9	continuation of run #21
23	STIM210	4	30	1.00E+11	4.43E+07	1	
24	STIM210	5	20	2.52E+10	3.36E+07	0	Run ended due to a power shutdown at the test laptop. While at other instances this was abrupt, here the laptop froze before crashing, allowing to shut down the beam before loss of data.
25	STIM210	5	20	3.50E+10	3.34E+07	0	Continuation of run #24, Premature end of power supply data due to a power shutdown at the test laptop
26	STIM210	5	20	--	--	--	beam was started for <1 second but UUT was not ready yet.
27	STIM210	5	20	7.36E+09	3.36E+07	--	Continuation of runs #24 and 25, Premature end of power supply data due to a power shutdown at the test laptop

Table 8: SEE: UUT-Overview on performed runs, total fluence and last failure state. Given here is only a brief overview on the pass/fail behavior of the UUTs as understood during conductance of the tests.

Energy [MEV]	List of Runs									
	STIM300					STIM210				
	#1	#2	#3	#4	#5	#1	#2	#3	#4	#5
200			14	12, 13		17, 18				
120	6	7, 8					19, 20			
60		9						21, 22		
30			10, 11						23	
20					15, 16					24, 25, 27

Energy [MEV]	Total fluence across runs / Failure state after last run of UUT									
	STIM300					STIM210				
	#1	#2	#3	#4	#5	#1	#2	#3	#4	#5
200			1.55E+10	2.90E+10		2.77E+10				
120	1.00E+11	2.13E+10					1.00E+11			
60		9.49E+10						9.99E+10		
30			1.00E+11						1.00E+11	
20					1.01E+11					6.76E+10

not tested at energy
passed at post-irradiation test
failed at post-irradiation test
no communication established at post-irradiation test

7.2.2 Supply currents during the irradiation

The UUTs had abrupt jumps in the supply current, both increasing and decreasing. After such a jump in supply current, the current remained approximately constant, sometimes slowly relaxing over time. In the majority of cases, power cycling reset the supply current to the normal level. These jumps could be up to the power supply limit of 1 A, accompanied by a drop in supply voltage due to the compliance limit set at the supply. These rather rare cases showed the classical characteristic of a single-event latch-up, where the UUT develops parasitic current routes in the semiconductor structure, leading to a short circuit. The majority of the current jumps were however of moderate to significant height in the order of magnitude of a few mA to a few 100 mA without showing clear signs of a latch-up. However, they may represent parts of the system latching with the current limited by other parts of the system.
The jumps in the supply current could also represent SEFIs, where parts of the system stop functioning or changing to an undefined mode of operation, leading to an increase or decrease of the current consumption.
Therefore, no differentiation between the different amplitudes of the current jumps or supposed latch-ups, has been done, only whether the current is increased or decreased afterwards has been recorded. A threshold of 10 mA was used to clearly distinguish between noise in the measured supply current and the jumps and then count the number of occurrences of these jumps. A calculation of the cross section was made (a measure for the likelihood of an event) for each proton energy by dividing the number of events by the total fluence. The results are plotted versus proton energy in Figure 25 and Figure 26. Error bars are calculated for a confidence level of 0.95 according to ESCC 25100.

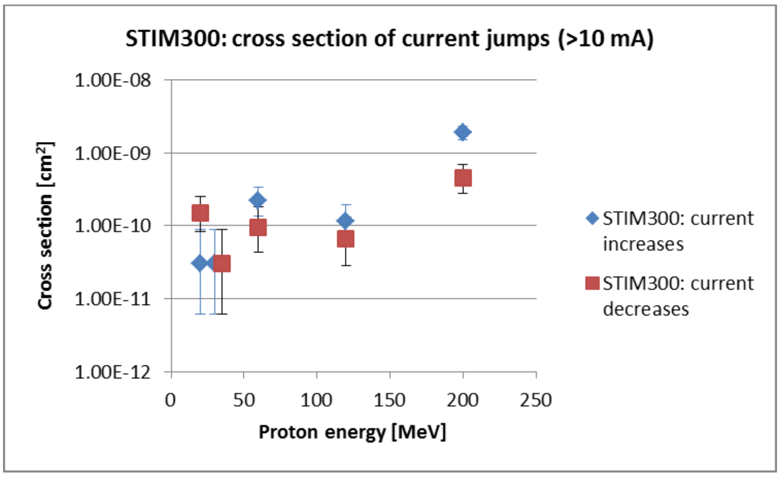


Figure 25: SEE: STIM300: Cross section evaluation of the current jumps versus proton energy. The values at 30 MeV overlap exactly and are shifted along the x-axis in this image for better visibility. A threshold of 10 mA from one data point to the next is applied when counting the current jumps.

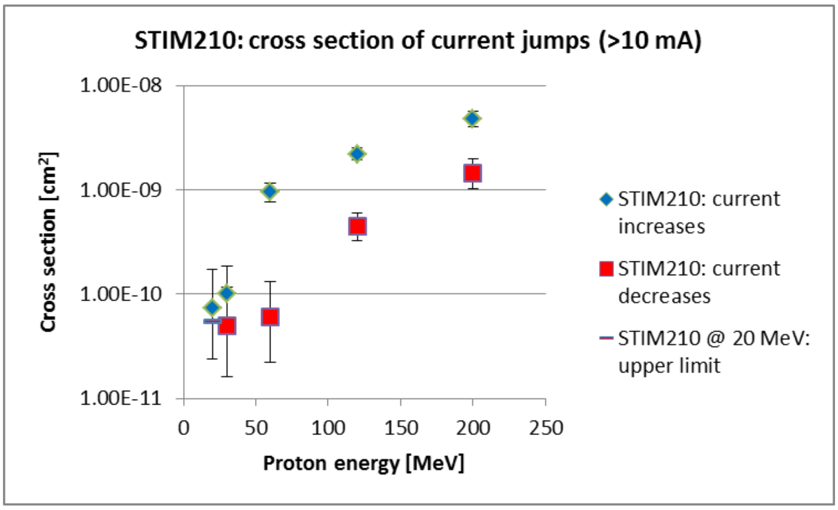


Figure 26: SEE: STIM210: Cross section evaluation of the current jumps versus proton energy. A threshold of 10 mA from one data point to the next is applied when counting the current jumps. At 20 MeV no such current decrease was observed, so only the statistical upper limit of the cross section is given.

In comparison the cross sections at high energies are lower for the STIM300 than for the STIM210 and at approximately the same level for lower energies. At or below 60 MeV additional effects due to TID may contribute. However for the STIM210, the rather strong correlation of the cross section with the proton energy down to the lowest energies of the tests indicate that the currents jumps are mostly given by single event effects. For the STIM300 at low energies this is not indicative from the evaluation.

7.2.3 Post-irradiation tests

An overview of the results of the post-irradiation tests is given in Table 9. The failure state after the last run at a given proton energy (in most instances, more than one run was performed to achieve the given total fluence) is provided.

Table 9: SEE: Overview of the results

Energy [MEV]	Total fluence across runs / Failure state after last run of UUT									
	STIM300					STIM210				
	#1	#2	#3	#4	#5	#1	#2	#3	#4	#5
200			1.55E+10	2.90E+10		2.77E+10				
120	1.00E+11	2.13E+10					1.00E+11			
60		9.49E+10						9.99E+10		
30			1.00E+11						1.00E+11	
20					1.01E+11					6.76E+10

not tested at energy
passed at post-irradiation test
failed at post-irradiation test
no communication established at post-irradiation test

At 200 MeV, all UUTs failed at relatively low fluences of less than 3E10 p/cm^2. In these cases, communication with the UUT was working, but other failures of the UUT were observed.
At energies of 120 MeV and below, the results seem less conclusive. There is no apparent trend or failure mode observable. Sometimes UUTs are passing at one energy and failing at the next lower energy.

7.2.4 UUT failure classification

After return to Sensonor, an initial inspection was done to verify the status of all tested units. The results from this inspection is shown in Table 10.

The results from further analysis are given in chapters below.

Table 10: Hardware failure classification, SEE test

Description	ID	Comment
STIM210 without HW failures after SEE testing	N25581824756125	This unit has recovered after radiation test after initially showing HW issues
	N25581824756127	
	N25581824756124	
STIM210 with HW failures after SEE testing	N25581824756128	
	N25581824756122	
STIM300 without HW failures after SEE testing	N25581820708894	
	N25581804460923	This unit has recovered after radiation test after initially showing HW issues
STIM300 with HW failures after SEE testing	N25581817663472	
	N25581820708868	
	N25581814582336	

7.2.5 Post SEE irradiation verification, functional UUTs

Bias offset and Scale Factor were measured in Sensonor's production line. The results from these tests have been compared to the results of identical measurements made before the TID radiation. A summary can be found in Table 11:

Table 11: Summary of results of functional parts after SEE-test

Product	Results		
	Gyro	Acc	Inc
STIM300	OK	NOK	NOK
STIM210	OK	N/A	N/A

The plots in Figure 27 to Figure 32 show the absolute value of the bias and scale factor drift between pre- and post-tests. The boxplots represent the interquartile range with the middle line representing the median. The full comparison of test results can be found in Appendix D.

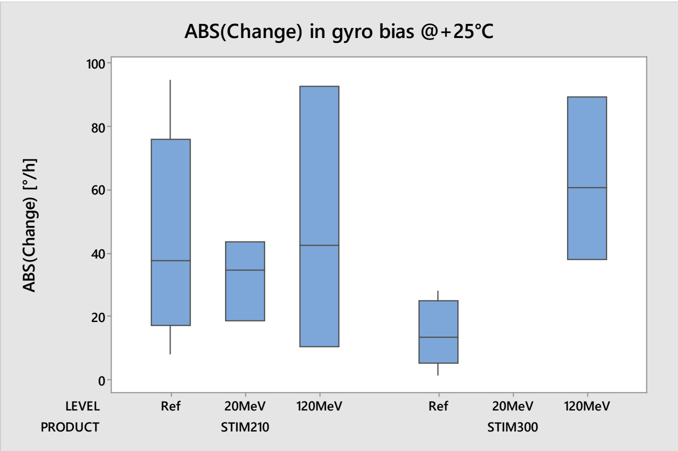


Figure 27 Change in gyro bias

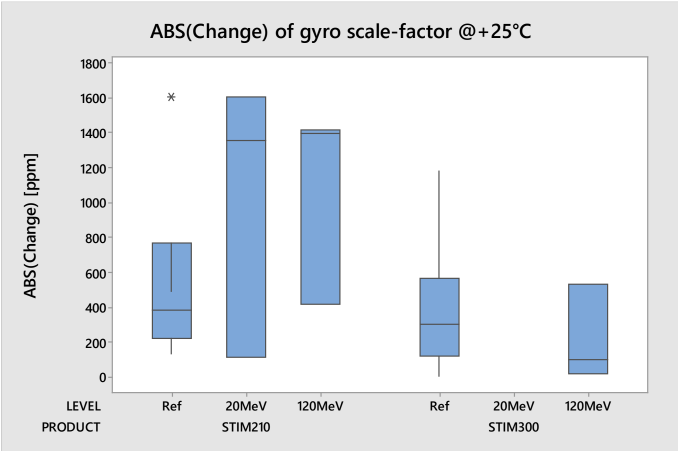


Figure 28 Change in gyro scale factor

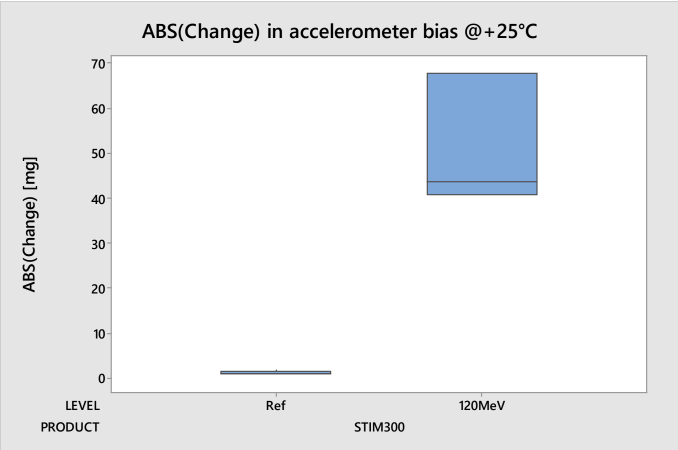


Figure 29 Change in accelerometer bias

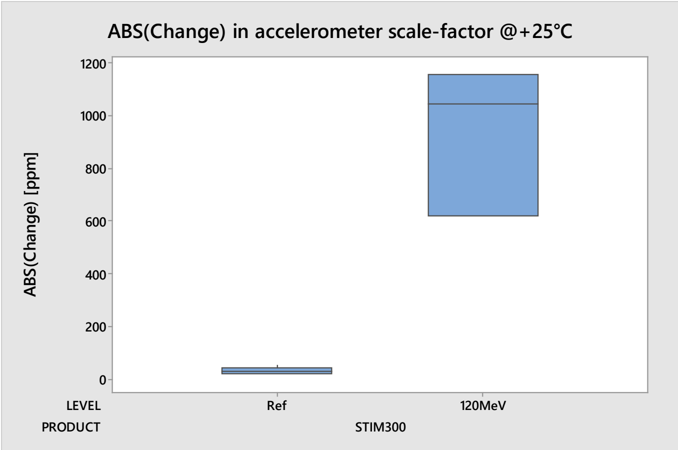


Figure 30 Change in accelerometer scale factor

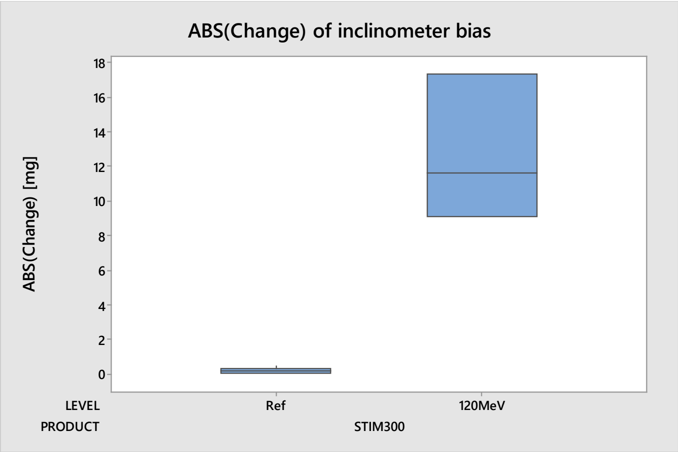


Figure 31 Change in inclinometer bias

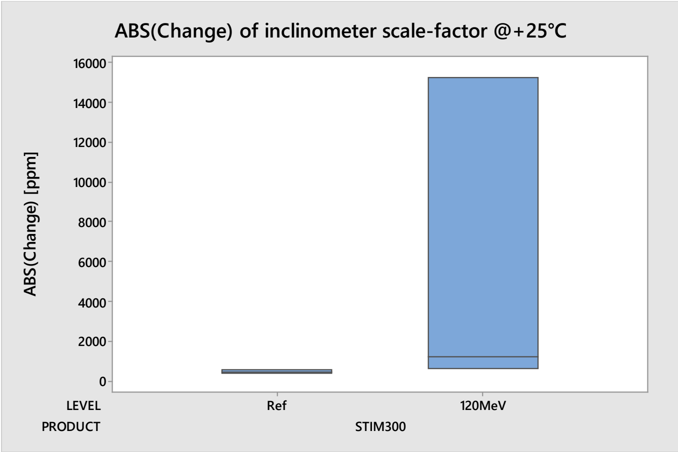


Figure 32 Change in inclinometer scale factor

7.2.6 Failure analysis of non-functional UUTs

Units indicating HW errors were opened for further analysis and repair. A thorough failure analysis has been performed on the modules to identify what electronic components have failed. All electronic components that had to be replaced in order to make the STIM210/STIM300 to power up with no error indication are described in this chapter. See Appendix E for details on the replaced electronics.

Figure 33 shows all failing electronic components for STIM300 modules that were irradiated in the SEE test. Figure 34 shows all failing electronic components for STIM210 modules that were irradiated in the SEE test. Figure 35 shows a Pareto of all electronic components that have failed during SEE test.

Several modules experienced multiple component failures. No assessment has been made as to whether any failure is derived from the radiation itself or is a consequence of other electronic failures.

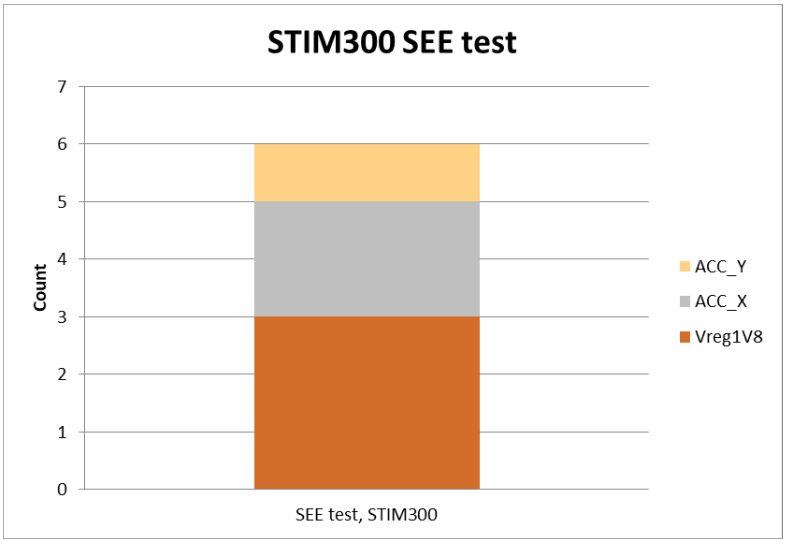


Figure 33: Failing electronics in STIM300 during SEE test

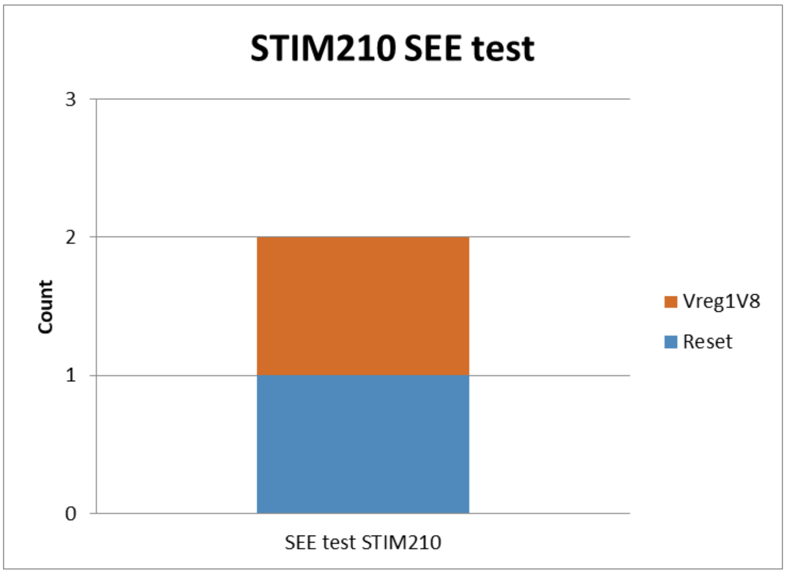


Figure 34: Failing electronics in STIM210 during SEE test

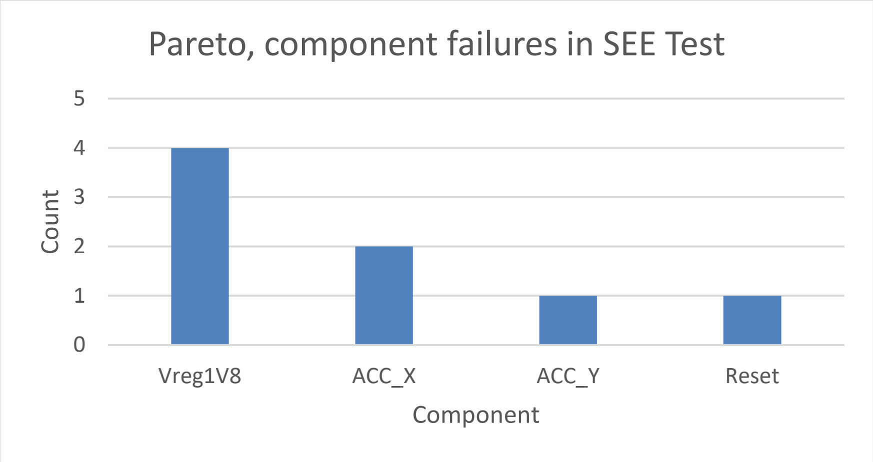


Figure 35: Pareto, Failing electronics in STIM210 and STIM300 during SEE test

7.2.7 Test after repair

After replacing components in all failing units necessary for powering up the STIM300 and STIM210 without error indication, the units were tested in a set of standard production test insertions. Overall results are shown in Figure 36.

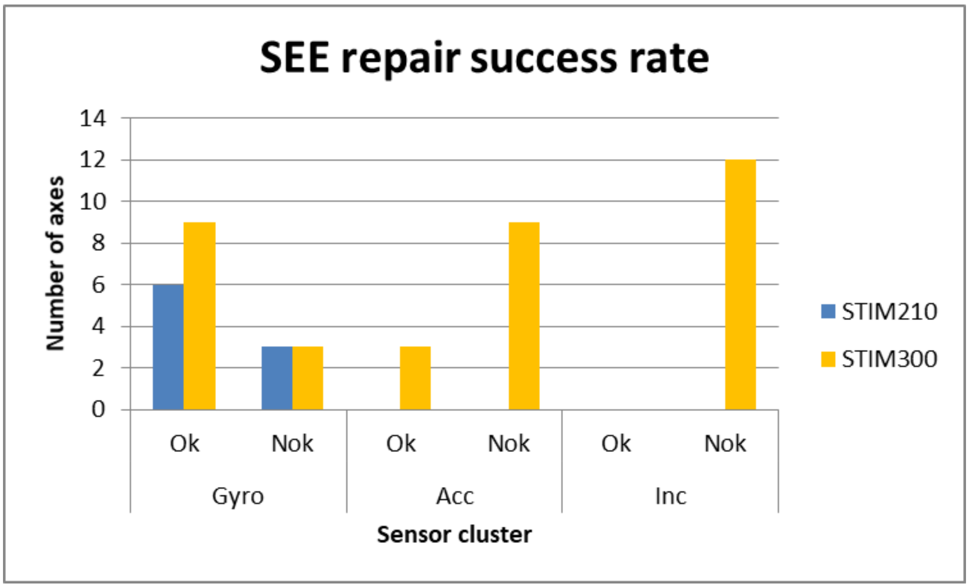


Figure 36: SEE success rate of repairs

8 Total Ionizing Dose Test

This Section features the description of the TID tests using the Co-60 source TK1000B at Fraunhofer INT and the equipment used for the tests. The results are shown in Section 8.2.

8.1 Execution of test

8.1.1 Facility

The TID tests of STIM210 and STIM300 were performed at the TK1000B facility at Fraunhofer INT. The gamma radiation has two levels of energy, 1.172 and 1.332 MeV. The dose rate can be varied from several krad/h down to a few rad/h. For this test, a dose rate of 1400 rad/h was chosen.

8.1.2 Sample holder

A custom-build sample holder (Figure 37) was manufactured to

- fix the samples under the radiation source
- dissipate heat from the UUT's
- ensure the samples are homogeneously irradiated

To fit the point symmetry of the Co-60 source, the UUTs were arranged in a circular pattern with 9.2 cm inner radius and 13.1 cm outer radius.
The aluminium base plate was used in the TID tests of both STIM210 and STIM300 with the PMMA top plate serving as a charge equalization layer.

The irradiation parameters correspond to a sample-distance of 34.1 cm from the source at TK1000B (Figure 38) to the object minimum.

Figure 37: TID: Aluminium Sample holder

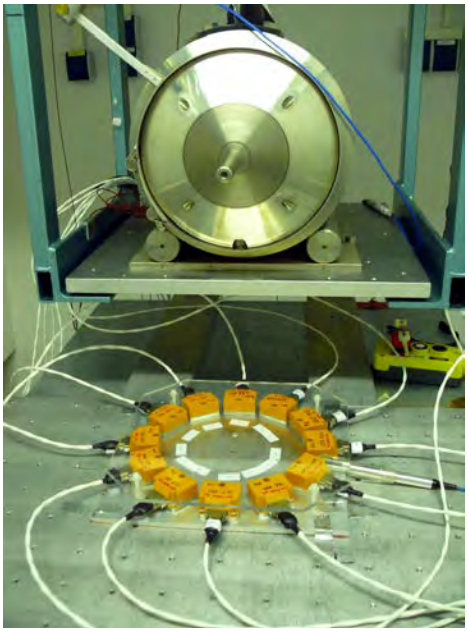


Figure 38: TID: Sample holder with PMMA top plate at TK1000B

8.1.3 Power conditioning and test setup

During the irradiation the samples were powered and operated according to the circuit-description of the irradiation test plan, see Figure 8. An HP E3631A power supply (Eq.Id E-PS3-001) was used for powering the UUT's during the STIM210 and STIM300 tests. The power supply unit was not calibrated but the voltage and current were checked with a calibrated Keysight 34401A digital multimeter (Eq-Id.: E-DMM-015, calibration due 05/2019), which was also used to measure the supply currents during the irradiation steps. To compensate for the voltage drop in the 10 m cables used to connect the supply outside the Co-60 chamber with the UUTs, the UUTs were biased at 5.2 V.

A ground potential point inside the chamber was used to ground the unbiased UUTs.
The cables used to bias or ground the UUTs were provided by Sensonor for the conduction of the tests. The cables were uniquely labelled at both ends to prevent mix up of the cables.

Table 12: TID: Biasing and test equipment

Equipment	Manufacturer	Model	Eq-ID	Calibration due
Power supply	HP	E3631A	E-PS3-001	n/a
Digital Multimeter	Keysight	34401A	E-DMM-015	05/2019
Ionization chamber	PTW	TW30012-1	D-IC-006	08/2019
Electrometer	PTW	UNIDOS webline T10022	D-DOSE-001	09/2019

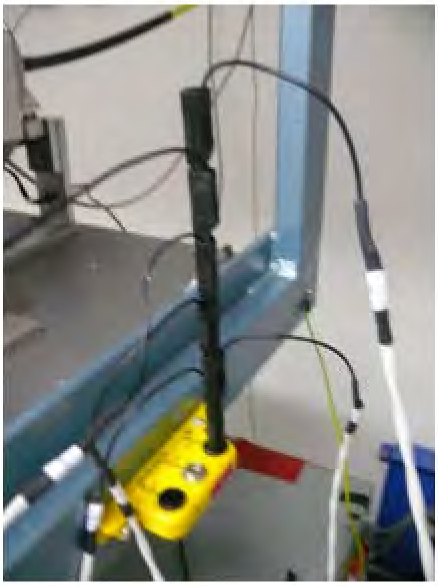


Figure 39: TID: Biasing and test equipment. Left side:power supply and multimeter outside of the chamber for UUT biasing. Right side: grounding of unbiased samples

8.1.4 Environmental variables

All irradiation steps were done in air. The samples at TK1000B were irradiated in ambient light. The parameters of the humidity and the temperature are given in the Table 14 and Figure 40.
In addition to the dosimetry system installed at TK1000B, the dose rate was checked during the irradiation with a calibrated ionization chamber (Table 13) positioned on the sample holder next to the UUTs. That data was not stored and only used for consistency checks during the campaigns.

Table 13: TID: Equipment for additional dosimetry

Equipment	Manufacturer	Model	Eq-ID	Calibration due
Ionization chamber	PTW	TW30012-1	D-IC-006	08/2019
Elektrometer	PTW	UNIDOS webline T10022	D-DOSE-001	09/2019

Table 14: TID: Environmental variables during irradiation of STIM210 and STIM300

Parameter	Value and Unit	Remarks
Humidity	34.4% ± 1.5%	Non-condensing, average and standard deviation from 2018-10-30 00:00 to 2018-11-01 12:00
Temperature	22.1 °C ± 0.1 °C	Average and standard deviation from 2018-10-30 00:00 to 2018-11-01 12:00

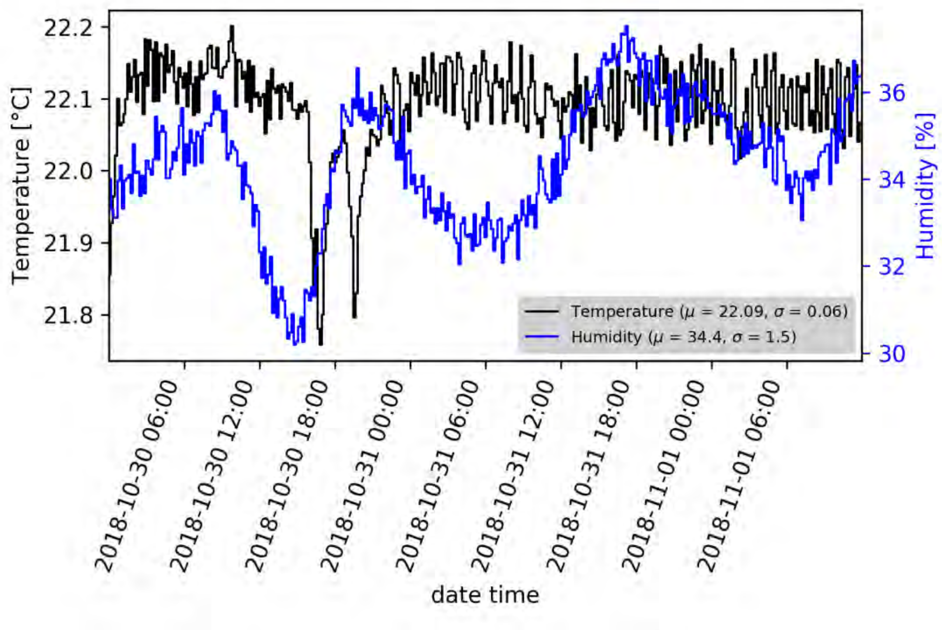


Figure 40: TID: Environment variables during the irradiation tests.

8.1.5 Measurement parameters

The combined supply current of all biased UUTs was measured during the irradiation steps with the equipment shown in Figure 39 and Section 8.1.3.
As one biased UUT was removed between the irradiation steps (Figure 9), the total current decreased accordingly from one irradiation step to the next.

Table 15: Measurement parameters

No.	Characteristics	Symbol	Test Conditions
1	Combined supply current of biased UUTs	I_{total}	V_{supply} = 5.2 V, number of UUTs depending on dose step (Figure 9)

8.1.6 Measurement procedures

Online measurements of the supply currents were programmed, controlled and stored using software written by Fraunhofer INT in LabView. Data points were taken each 2 seconds.

8.2 Results

8.2.1 Irradiation steps

Table 16: TID: STIM300: TID irradiation steps

#	Dose steps	Total Dose [krad(Si)]	Dose rate [krad(Si)/h]	Start	Stop	Duration [h:m:s]
1	0 krad(Si) → 3 krad(Si)	3	1.40	30.10.2018 05:58	30.10.2018 08:07	02:08:36
2	3 krad(Si) → 5 krad(Si)	5	1.40	30.10.2018 09:43	30.10.2018 11:09	01:25:44
3	5 krad(Si) → 7 krad(Si)	7	1.40	30.10.2018 11:37	30.10.2018 13:03	01:25:45
4	7 krad(Si) → 10 krad(Si)	10	1.40	30.10.2018 13:57	30.10.2018 16:06	02:08:38
5	10 krad(Si) → 15 krad(Si)	15	1.40	30.10.2018 16:41	30.10.2018 20:16	03:34:21
6	15 krad(Si) → 30 krad(Si)	30	1.40	30.10.2018 20:47	31.10.2018 07:30	10:42:57

Table 17: TID: STIM210: TID irradiation steps

#	Dose steps	Total Dose [krad(Si)]	Dose rate [krad(Si)/h]	Start	Stop	Duration [h:m:s]
1	0 krad(Si) → 3 krad(Si)	3	1.40	31.10.2018 08:42	31.10.2018 10:51	02:08:36
2	3 krad(Si) → 5 krad(Si)	5	1.40	31.10.2018 11:17	31.10.2018 12:42	01:25:44
3	5 krad(Si) → 7 krad(Si)	7	1.40	31.10.2018 13:06	31.10.2018 14:32	01:25:45
4	7 krad(Si) → 10 krad(Si)	10	1.40	31.10.2018 14:58	31.10.2018 17:07	02:08:37
5	10 krad(Si) → 15 krad(Si)	15	1.40	31.10.2018 17:32	31.10.2018 21:07	03:34:21
6	15 krad(Si) → 30 krad(Si)	30	1.40	31.10.2018 21:23	01.11.2018 08:06	10:42:57

The dose steps were within timing accuracies (<1 second) at the scheduled total dose levels.

8.2.2 Supply currents during the irradiation

Figure 41 and Figure 42 show the average supply currents drawn by the UUTs versus total ionizing dose over the whole dose range. For a detailed view of current at each step, refer to Appendix A.

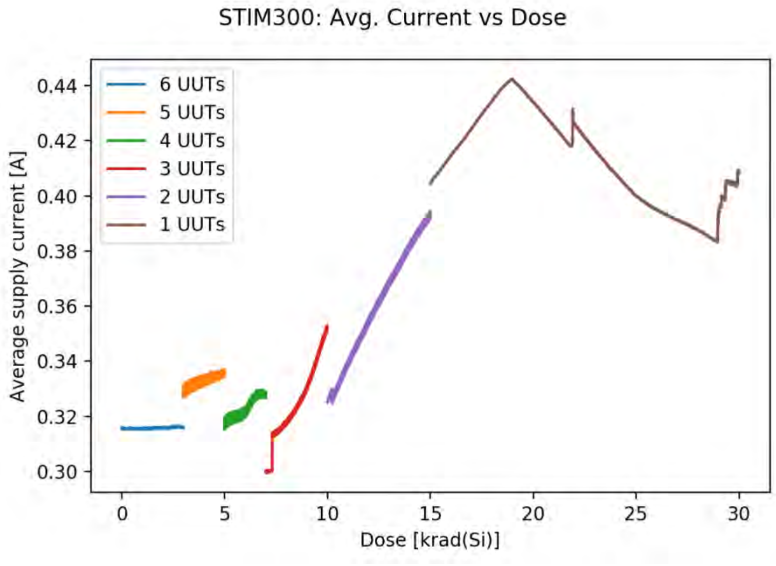


Figure 41: TID test of STIM300:Average supply current per UUT vs. total ionizing dose

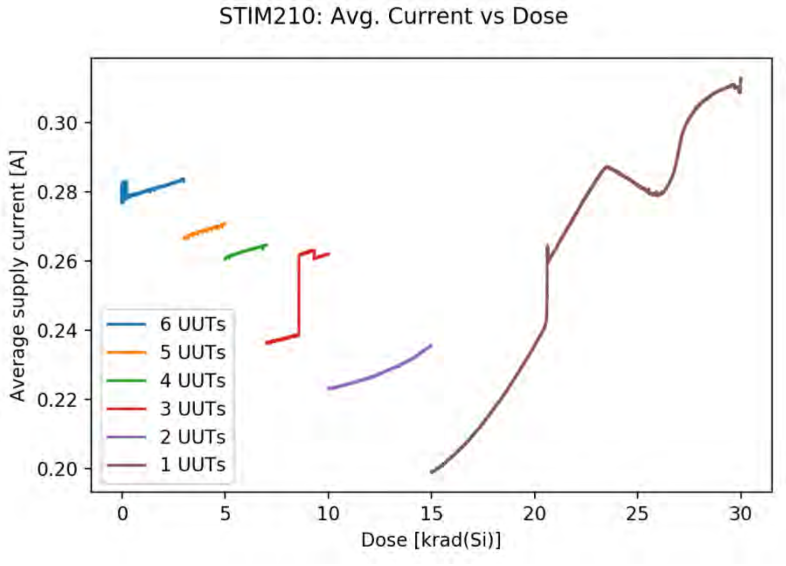


Figure 42: TID test of STIM210: Average supply current per UUT vs. total ionizing dose

8.2.3 Diagnostic test between irradiation steps

A pre-irradiation diagnostic read-out was performed on all UUT's. A post-irradiation diagnostic test was performed on all remaining UUT's after the completion of each dose step. Given here is only a brief overview on the pass/fail behavior of the UUTs as understood during conductance of the tests. All failing UUTs have undergone failure analysis.

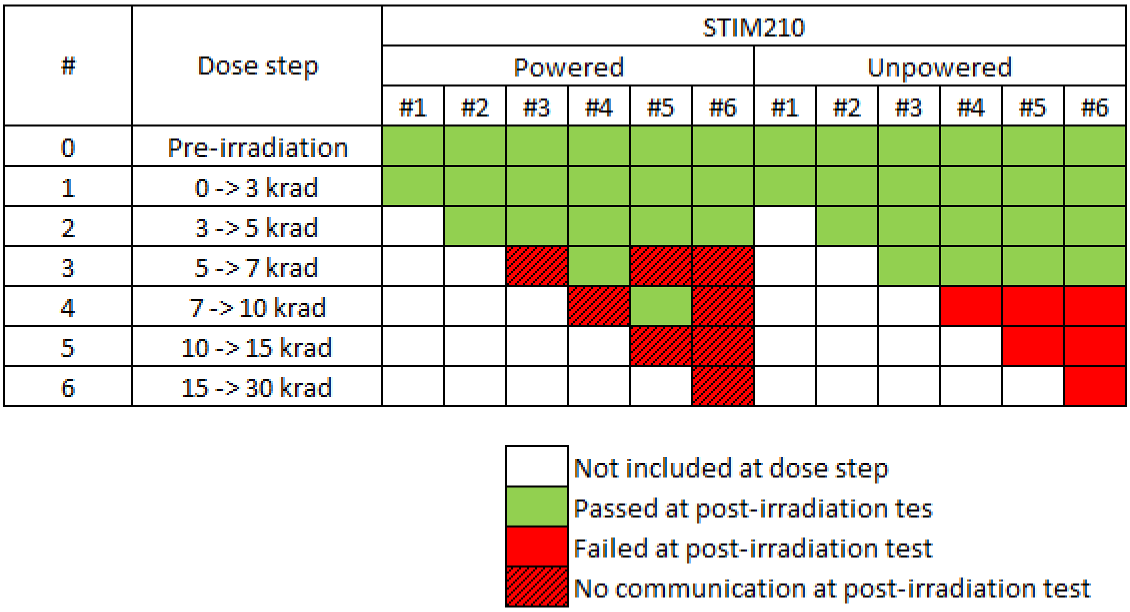


Figure 43: TID test of STIM210: Overview of results

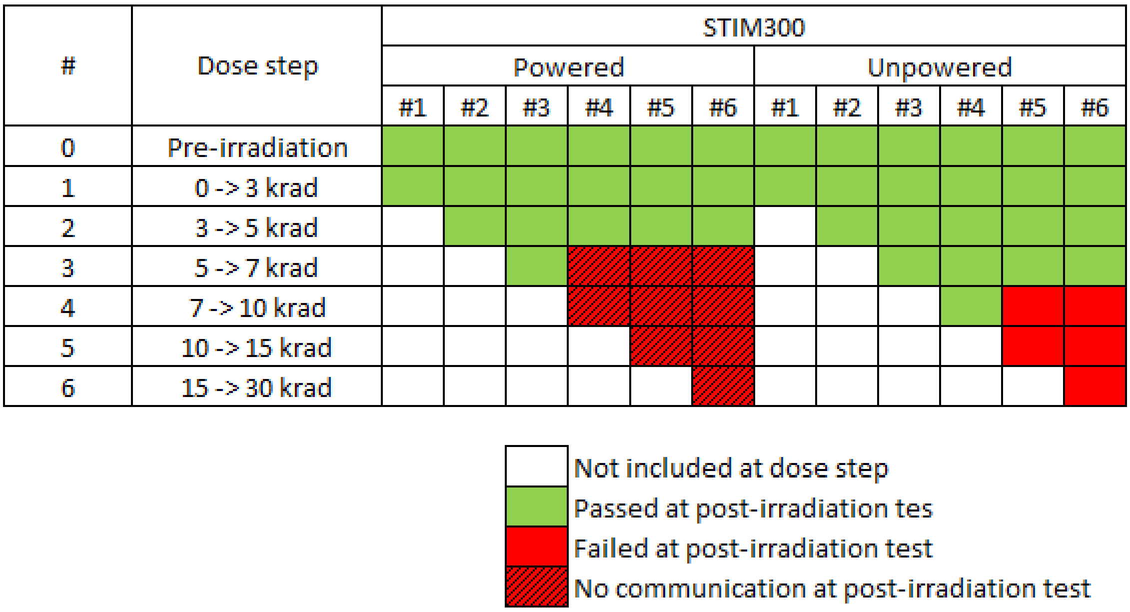


Figure 44: TID test of STIM300: Overview of results

8.2.4 UUT failure classification

After return to Sensonor, an initial inspection was done to verify the hardware status of all irradiated units. The results from this inspection are shown in Table 18.

The results from further analysis are given in chapters 8.2.5 and 8.2.6.

Table 18: Hardware failure classification, TID test

Description	ID	Total Dose [krad]	Powered/ Unpowered
STIM210 without HW failures after TID testing	N25581824756143	3	P
	N25581824756160	5	P
	N25581824756175	3	U
	N25581824756158	5	U
	N25581824756169	7	U
STIM210 with HW failures after TID testing	N25581824756157	7	P
	N25581824756150	10	P
	N25581824756162	15	P
	N25581824756166	30	P
	N25581824756173	10	U
	N25581824756168	15	U
	N25581824756165	30	U
STIM300 without HW failures after TID testing	N25581817664570	3	P
	N25581820707845	5	P
	N25581817663459	7	P
	N25581804458810	3	U
	N25581817664560	5	U
	N25581748366700	7	U
	N25581748367781	10	U
STIM300 with HW failures after TID testing	N25581820707843	10	P
	N25581818673709	15	P
	N25581820706758	30	P
	N25581804458811	15	U
	N25581820707844	30	U

8.2.5 Post TID irradiation verification, functional UUTs

Bias offset and Scale Factor were measured in the Sensonor production line. The results from these tests have been compared to the results of identical measurements made before the TID radiation. A summary can be found in Table 19

Table 19: Summary of results of functional parts after TID-test

Product	Results		
	Gyro	Acc	Inc
STIM300	OK	NOK	NOK
STIM210	OK	N/A	N/A

The plots in Figure 45 to Figure 50 show the absolute value of the bias and scale factor drift between pre- and post-tests. The boxplots represent the interquartile range with the middle line representing the median. The full comparison of test results can be found in Appendix C.

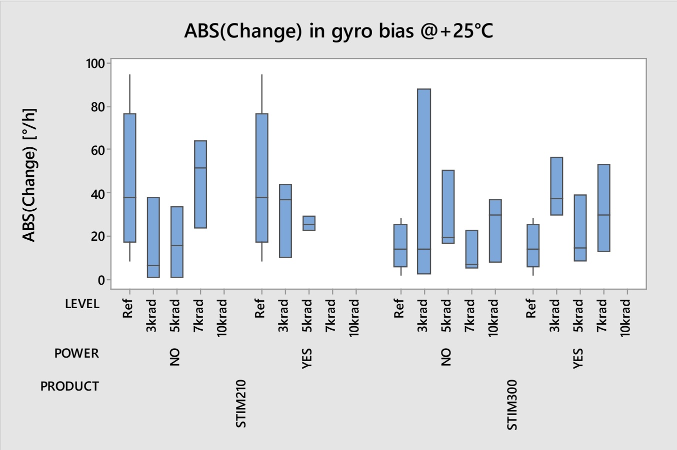


Figure 45 Change in gyro bias

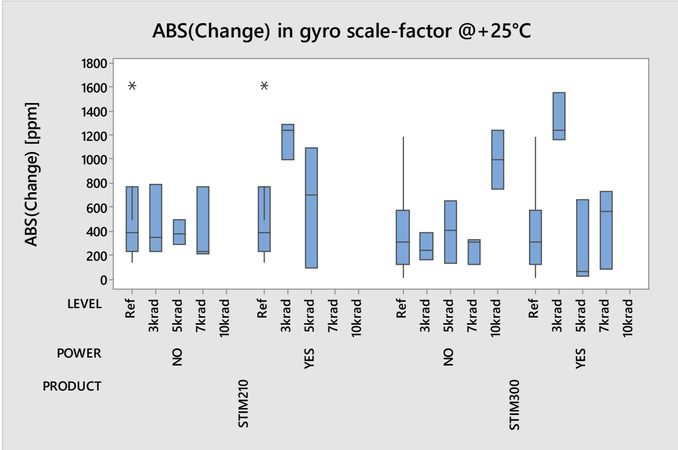


Figure 46 Change in gyro scale factor

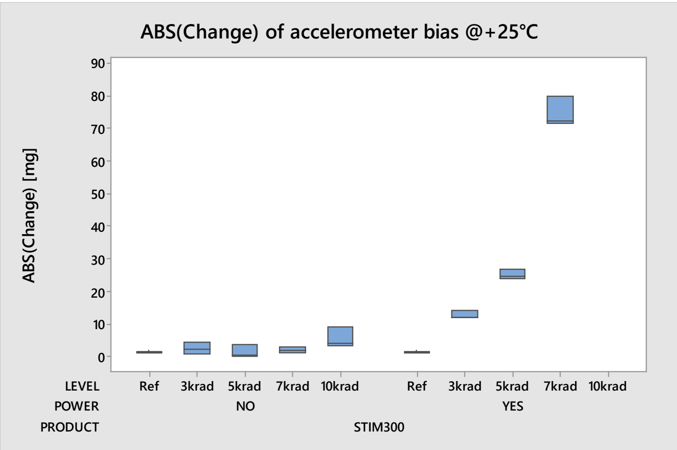


Figure 47 Change in accelerometer bias

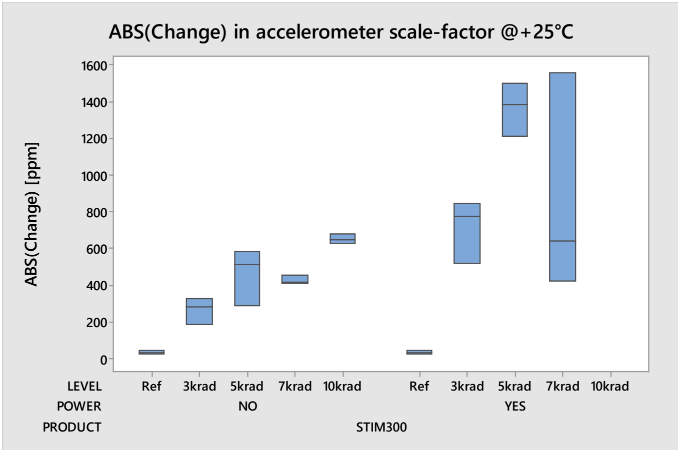


Figure 48 Change in accelerometer scale factor

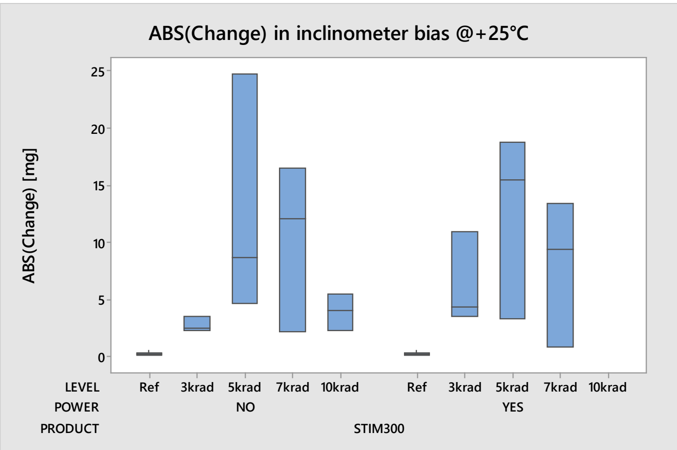


Figure 49 Change in inclinometer bias

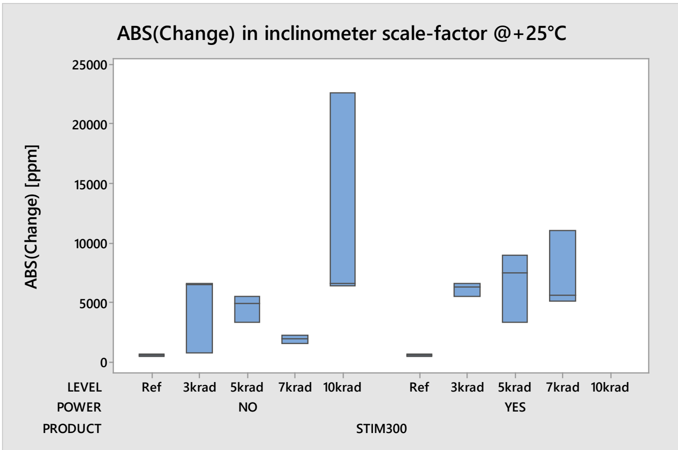


Figure 50 Change in inclinometer scale factor

8.2.6 Failure analysis of non-functional UUTs

Units indicating HW errors were opened for further analysis and repair. A thorough failure analysis was performed to identify electronic components that failed. The failing electronic components were replaced in order to power up the STIM210/STIM300 with no error indication.

Figure 51 shows the failing electronics for the powered STIM300 modules. Figure 52 shows the failing electronics for the unpowered STIM300 modules. Figure 53 shows the failing electronics for the powered STIM210 modules. Figure 54 shows the failing electronics for the unpowered STIM210 modules. Finally, Figure 55 shows a Pareto of the electronic components that have failed during TID test. See Appendix E for further details on the replaced electronics.

Several modules experienced multiple component failures. No assessment has been made as to whether any failure is derived from the radiation itself or is a consequence of other electronic failures.

Note that the total dose indicated in the plots for the TID tests indicates the total dose each component has been exposed to, not necessarily at what dose the failure first occurred.

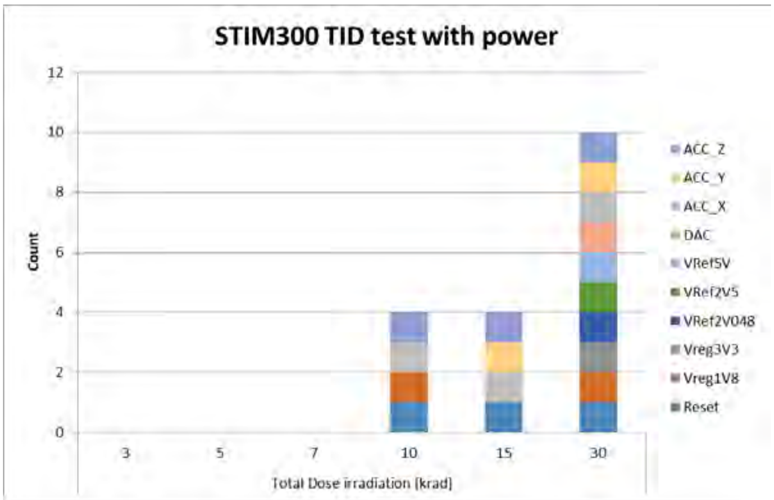


Figure 51: Failing electronics in powered STIM300 during TID test

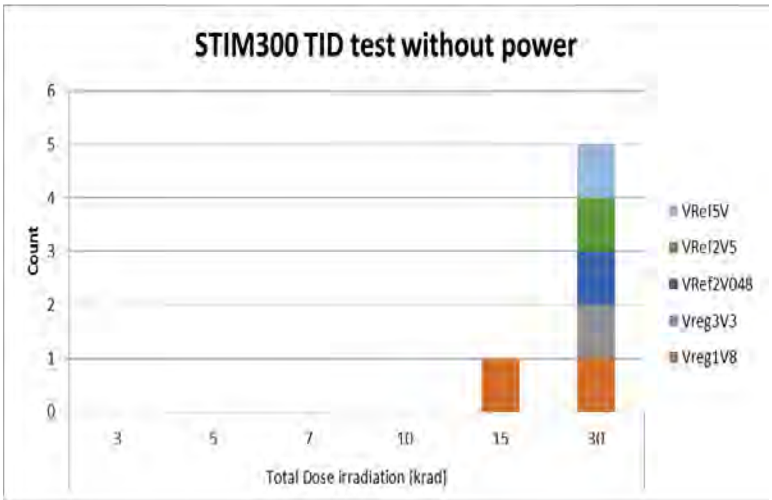


Figure 52: Failing electronics in unpowered STIM300 during TID test

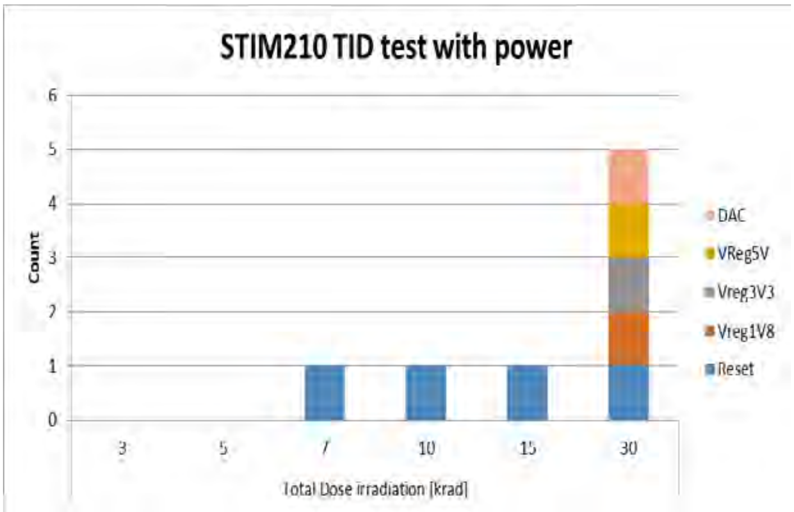


Figure 53: Failing electronics in powered STIM210 during TID test

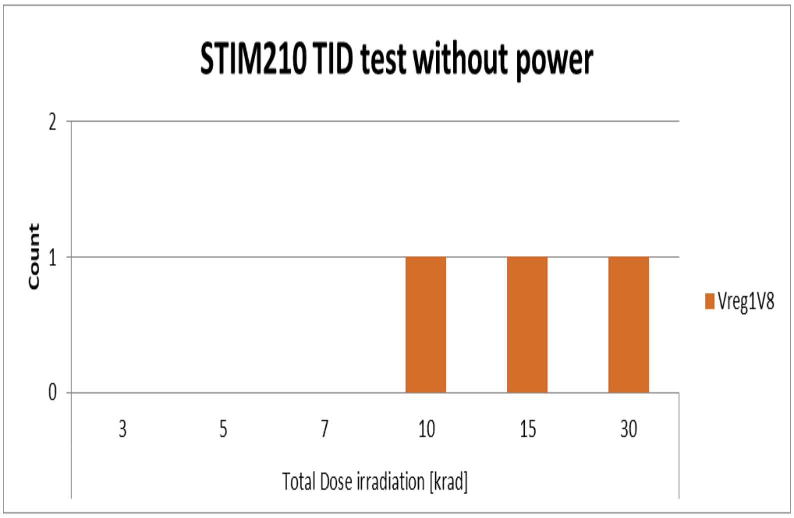


Figure 54: Failing electronics in unpowered STIM210 during TID test

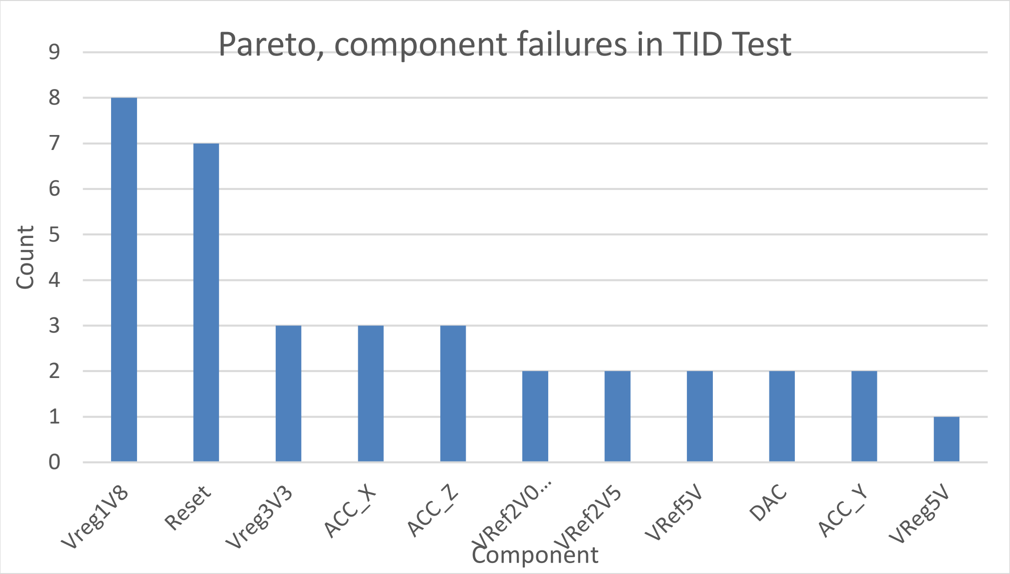


Figure 55: Pareto, Failing electronics in STIM210 and STIM300 during TID test

8.2.7 Test after repair

After replacing components in all failing units necessary for powering up without error indication, the units were tested in a set of standard production test insertions. Results are shown in Figure 56.

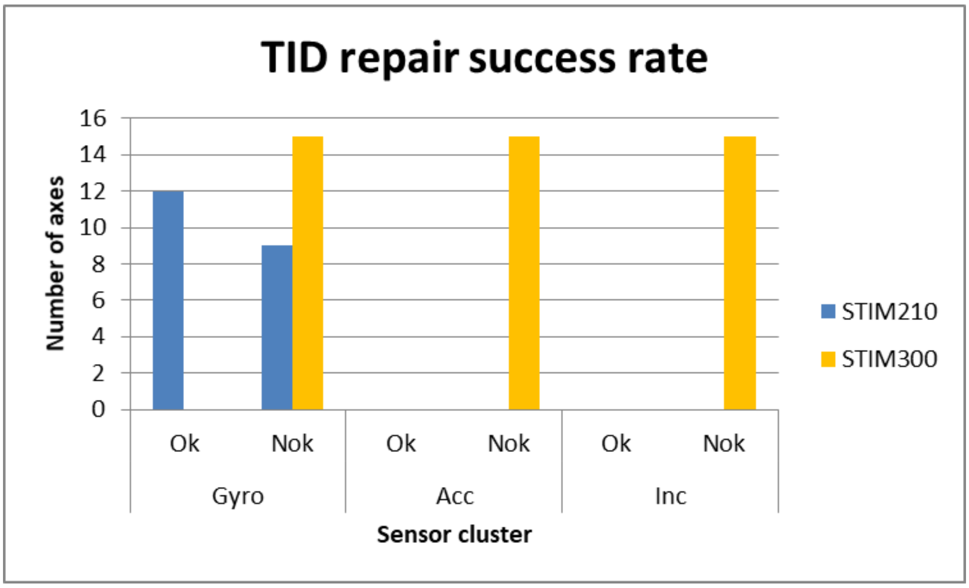


Figure 56: TID success rate of repairs

9 Discussion of results

9.1 Technology Acceptance Test

The TA tests are by large the same type of tests used in Sensonor's standard product qualification program. All test-steps were passed without any non-functional or failing UUTs, ref. Table 3, verifying that the STIM210 and STIM300 technology is suited for space-applications.

9.1.1 Post TA Verification

With reference to the pre- and post-test comparison, ref. Appendix B, the following observations are made:

- STIM210 Scale factor error shows a shift of -2958 ppm on the X-axis of N25581824753919. This is observed on one of six axes
- One STIM210 reference shows a Scale factor error shift of -1611 ppm on the Y-axis of N25581824753898. This is observed on one of six axes

The observed shifts in gyro scale-factor of STIM210 have also been observed in Sensonor's standard product qualification program and is not considered as an abnormal behavior.

9.2 Single Event Effect Test

9.2.1 Fluence and assessment of SEE in LEO missions

A simplified assessment of the radiation levels found in low-Earth orbit missions has been done. It can only serve as an illustration on what to expect. The radiation levels for a specific mission have to be determined properly for a specific mission.
As an example a 10 year mission in heliosynchronous orbit at 800 km altitude is considered. The tool used for generation of the orbit and estimation of the radiation environment and levels is the Space Environment Information System (SPENVIS) and the tools and models contained therein. As discussed in chapter 9.3.1, a relevant thickness of the aluminium shielding is 14mm. Using the MFLUX tool in SPENVIS, the shielded flux of protons behind 11.1 mm aluminium has been calculated (the next lower value from 14 mm, as only limited values are allowed in the tool), ref. Figure 57. In this example the highest contribution in the energy spectrum comes from protons of approx. 50-100 MeV energy with fluxes in the order of 100 p/cm^2/s and thus accumulates to approx. 3.2E10 p/cm^2 over the 10 year mission.

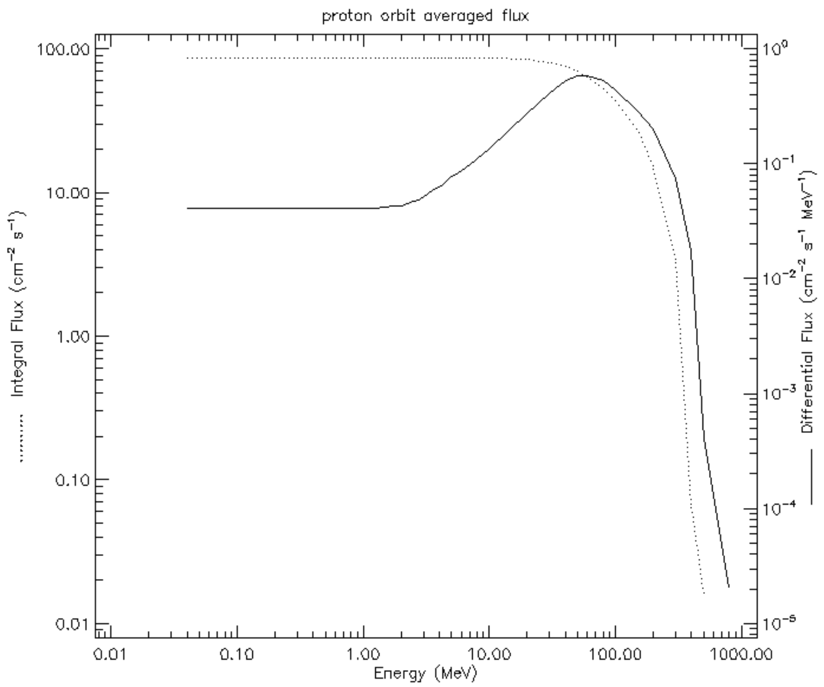


Figure 57: MFLUX results of the proton fluences behind 11.1 mm Al on an example LEO mission (800 km, 10 years, heliosynchronous)

The cross section has been experimentally derived for STIM210 and STIM300. Cross section for STIM210 correlates well with proton energy level, suggesting that the cross section reflects single-events only. For STIM300 the cross section is somewhat lower at higher proton energy levels and the correlation to proton energy level is not as evident.
For single event effects, the results indicate that there will be several 10s of events if flying the STIM210/STIM300 for 10 years with a spacecraft (assuming heliosynchronous 800 km orbit) with an aluminium wall thickness of 11mm.

9.2.2 Post SEE irradiation verification, functional UUTs

With reference to the pre- and post-test comparison, ref. Appendix D, the following observations are made:

- STIM300: An rms shift of approximately 70 mg in accelerometer bias at +25 °C is observed (ref. *Figure 123*). Also seen over temperature (ref. *Figure 131*)
- STIM300: A shift in the accelerometer scale factor is observed (ref Figure 138 to Figure 140)
- STIM300: An rms shift of approximately 13 mg in inclinometer bias at +25 °C is observed (ref. *Figure 126*)
- STIM300: A shift in the inclinometer scale factor is observed (ref Figure 141 to Figure 143)
- STIM210 gyro Scale Factor error is somewhat increased for one axis (approximately -1500 ppm), see *Figure 149*

As shifts are seen on all accelerometers and inclinometers, main suspect points towards the common electronics to these sensors, e.g. voltage reference and/or ADC. Investigations into the observed shifts have not been performed.

The observed shifts in gyro scale-factor of STIM210 have also been observed in Sensonor's standard product qualification program and is not considered as an abnormal behavior.

9.2.3 Analysis of failing parts

Looking at the pareto of failing UUTs, ref Figure 35 in section 7.2.6, the 1.8V regulator (LT1763CDE-1.8#PBF from Linear Technologies) strikes out as being more sensitive to radiation than other components. Also the reset-circuit (TPS3808G01DBVTG4 from Texas Instruments) and accelerometers are failing.

9.3 Total Ionizing Dose Test

9.3.1 TID level

A simplified assessment of the radiation levels found in low-Earth orbit missions has been done. It can only serve as an illustration on what to expect. The radiation levels for a specific mission have to be determined properly for that mission.
As an example a 10 year mission in heliosynchronous orbit at 800 km altitude is considered. The tool used for generation of the orbit and estimation of the radiation environment and levels is the Space Environment Information System (SPENVIS) and the tools and models contained therein.
To estimate the total ionizing dose behind aluminium shielding, e.g. the outer hull of the satellite, a SHIELDOSE2Q simulation is used, ref. Figure 58. This is a standard tool for this type of estimation. However it has some intrinsic limitations and may not be fully applicable to the STIM210 or STIM300. This is mainly because the total dose is simulated in silicon positioned directly behind the aluminium shielding, whereas in the UUTs tested here are more complex and feature a thick aluminium package themselves.

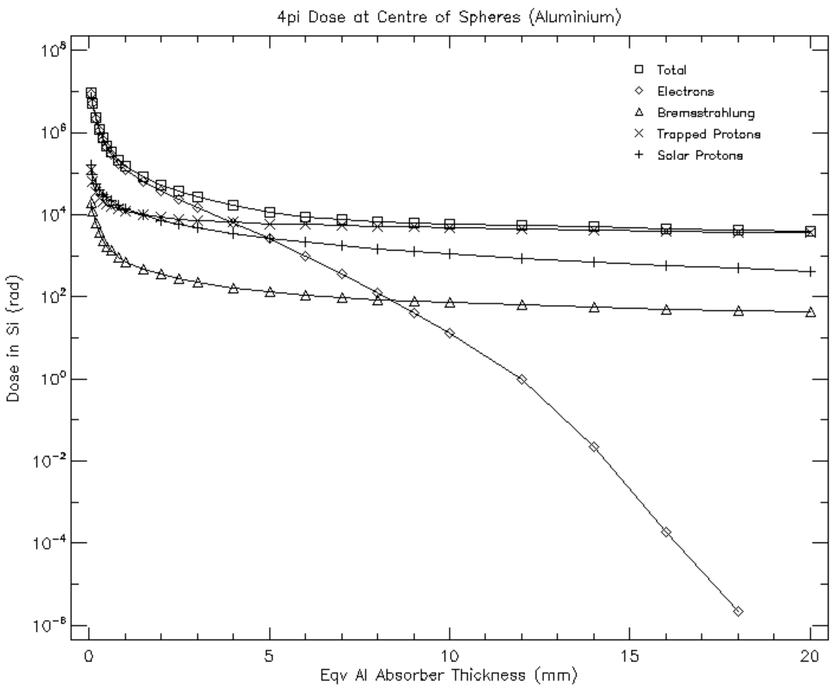


Figure 58: SHIELDOSE2Q results of the total dose behind aluminium on an example LEO mission (800 km, 10 years, heliosynchronous)

The diagnostic test performed after each irradiated dose, ref. Figure 43 (STIM210) and Figure 44 (STIM300), combined with the post-tests performed on parts passing the TID-tests, ref. Appendix C, show that the gyros in both STIM210 and STIM300 withstands a TID level of up to at least 5 kRad while powered and up to 7 kRad in an un-powered condition.

From the simulation, ref. Figure 58, behind 14 mm of aluminium shielding the total dose over 10 years drops below 5 krad(Si).

Even though the STIM300 accelerometers and inclinometers all passed the diagnostic test up to a TID level of 5 kRad for powered UUTs and 7 kRad for un-powered UUTs, the post-tests, ref. Appendix C, reveal that exposure to radiation results in significant shifts in bias and scale-factor:

- An rms shift of approximately 30 mg in accelerometer bias at +25 °C is observed (ref. *Figure 94*). Also seen over temperature (ref. *Figure 102*)
- An rms shift of approximately 11.5 mg in inclinometer bias at +25 °C is observed (ref. *Figure 96*)
- Scale Factor error for accelerometer and inclinometer is significantly increased (see Figure 108 and Figure 111)

The STIM300 accelerometers and inclinometers and/or their circuitry have shown negative effect from radiation. The bias and scale factor have drifted significantly already at 3 krad dose in the TID test. For the accelerometers, a robustness against higher dose levels is observed when the STIM300 is unpowered when compared to powered units (ref Figure 51 and Figure 52).

As shifts are seen on all accelerometers and inclinometers, main suspect points towards the common electronics to these sensors, e.g. voltage reference and/or ADC. Detailed investigations into the observed shifts have not been performed.

9.3.2 Analyses of failing parts

Looking at the pareto of failing UUTs, ref Figure 55, there are some components that strikes out as being more sensitive to radiation than other, in particular the 1.8V regulator (LT1763CDE-1.8#PBF from Linear Technologies) and the reset-circuit (TPS3808G01DBVTG4 from Texas Instruments). The reset-circuit only failed when the UUT was powered as was also the case for the accelerometers and the DAC.

10 Conclusions

Both STIM210 and STIM300 passed the TA test verifying that the products have a general robustness to function in Space.

The cross section related to SEE has been established for STIM210 and STIM300. In the simulated case of a 10 year mission in heliosynchronous orbit at 800 km with 11.1mm aluminum shielding, several 10s of events should be expected. This is also in line with earlier observations at LEO orbits between 700 and 800km (outside the SAA). Users should address this by current monitoring and in case of an current increase restart the component by cycling power to bring it back to normal operation.

Further results from the test campaign indicate that the gyros in STIM210 and STIM300 survives a TID level up 5kRad when powered up and up to 7 kRad when unpowered. These radiation levels are considered within acceptable range for many LEO operations.

The accelerometers and inclinometers shows a degradion when exposed to radiation.

This leads us to conclude that unless accelerometer/inclinometer measurement is required, it is adviseable to use the STIM210 which is not equipped with these sensors. In the event a STIM300 is needed, considerations should be made to shield the unit to avoid a radiation exposure dose of a magnitude that can lead to sensor degradation and/or break-down.

A Supply Current, TID test

Figure 59 and Figure 60 show supply current data for the individual dose steps. Large jumps from one irradiation step to another may be due to the number of UUTs changing from step to step (shown is the total current divided by the number of UUTs).

Noticeable irregularities can be seen in the 5 krad(Si) to 7 krad(Si) and in the 15 krad(Si) to 30 krad(Si) step for both the STIM210 and STIM300.

Furthermore to some extent the STIM210 shows a regular pattern of reduced current spikes. From the data it cannot be concluded whether this is a dose or a time effect.

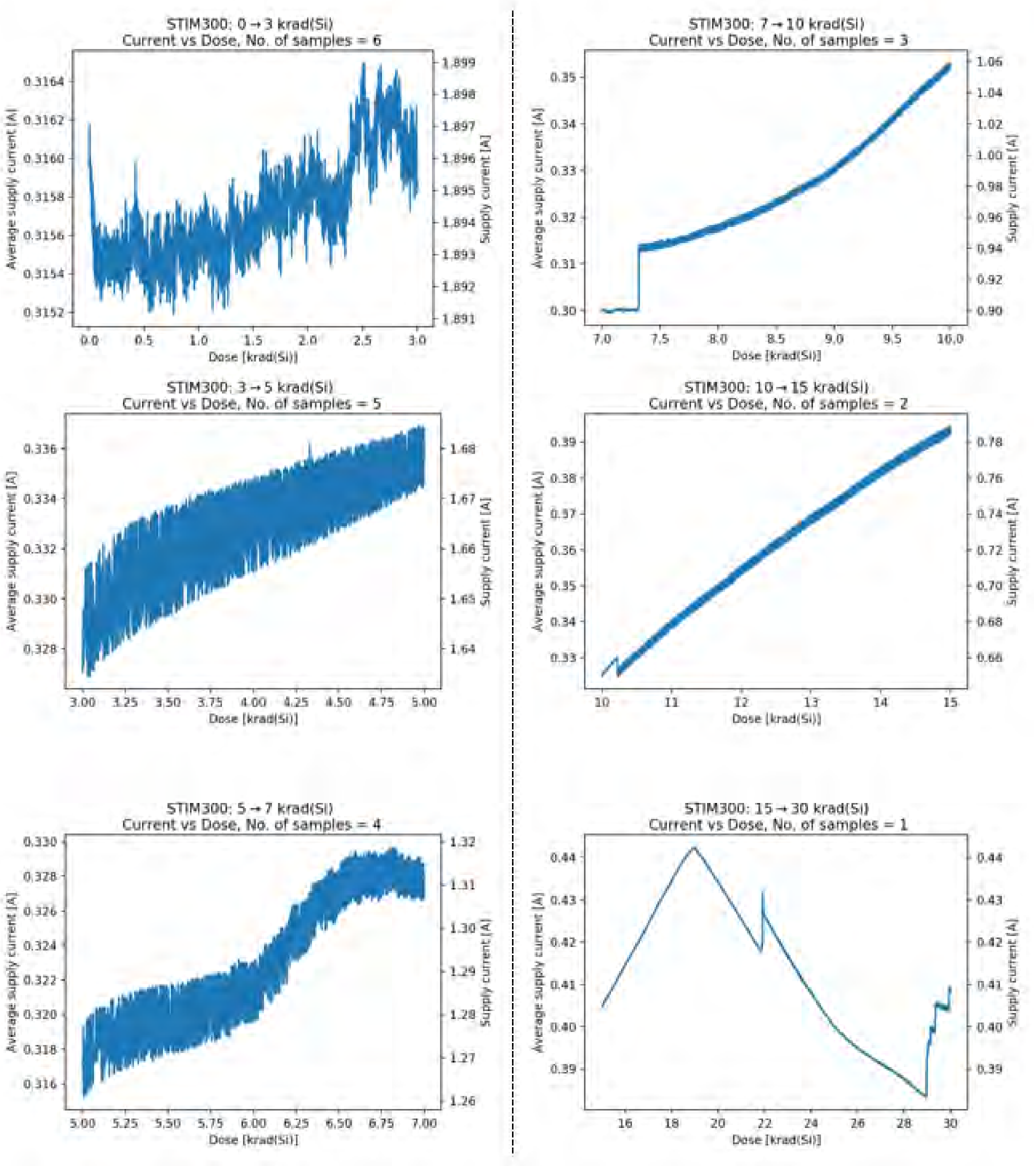


Figure 59: TID test of STIM300: Average supply current vs. total ionizing dose (individual dose steps)

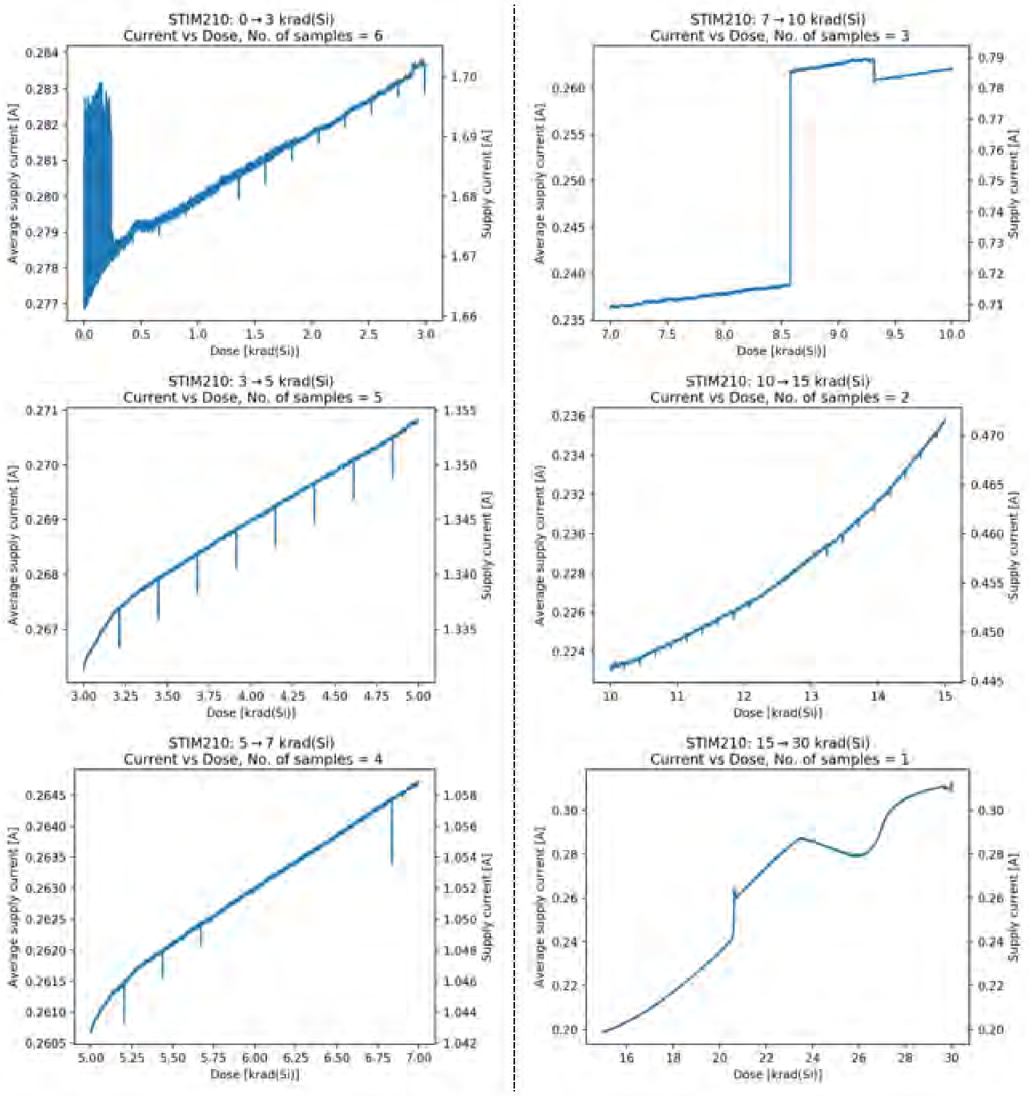


Figure 60: TID test of STIM210: Average supply current vs. total ionizing dose (individual dose steps)

B Production Test results comparisons before and after Technology acceptance test

The following figures shows the performance before and after TA test on the key parameters bias shift and scale factor error

- **STIM300**

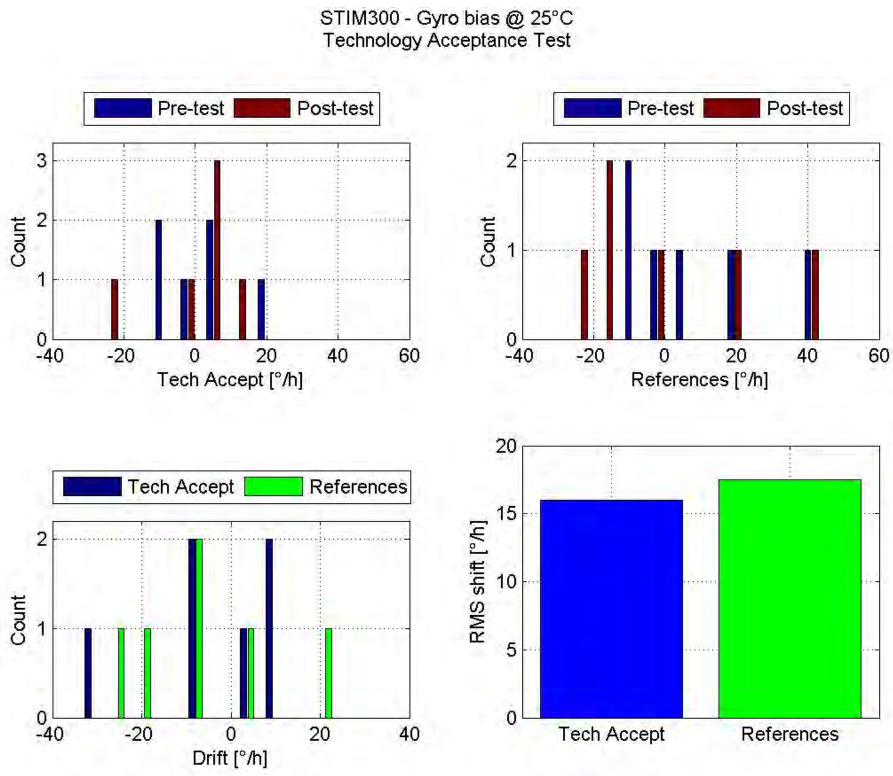


Figure 61 STIM300 Gyro bias at +25 °C before and after TA test

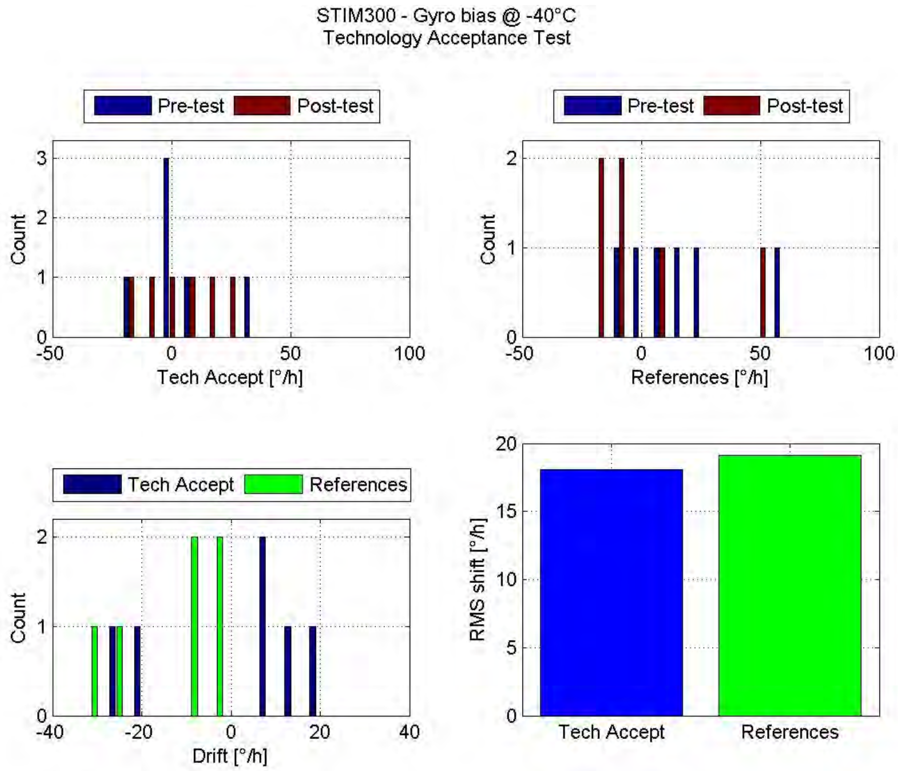


Figure 62 STIM300 Gyro bias at -40°C before and after TA test

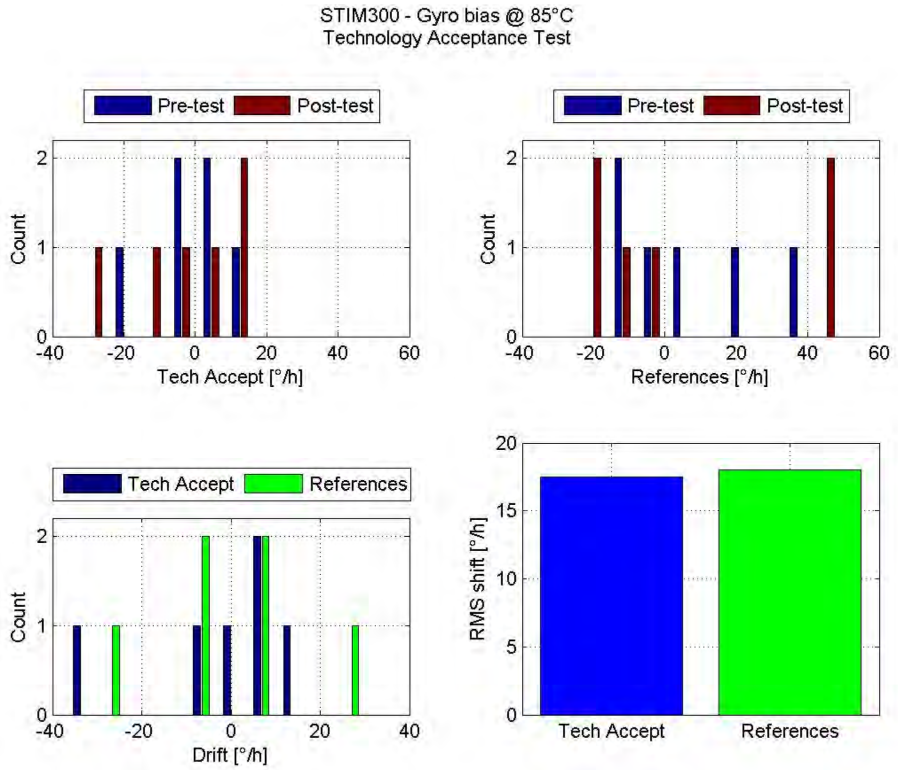


Figure 63 STIM300 Gyro bias at +85 °C before and after TA test

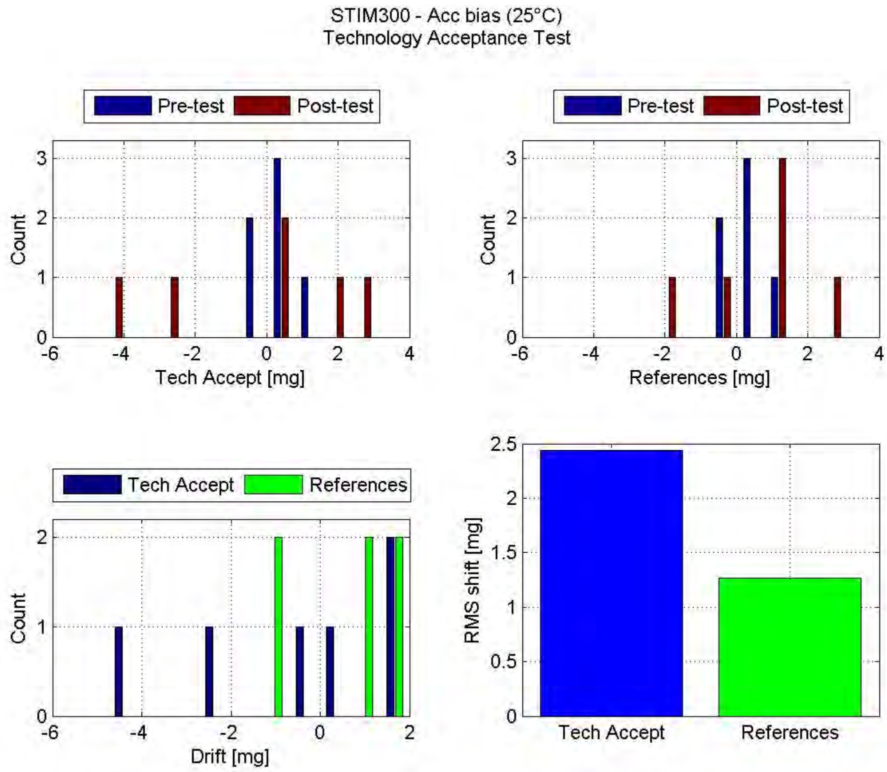


Figure 64 STIM300 Accelerometer bias at +25 °C before and after TA test

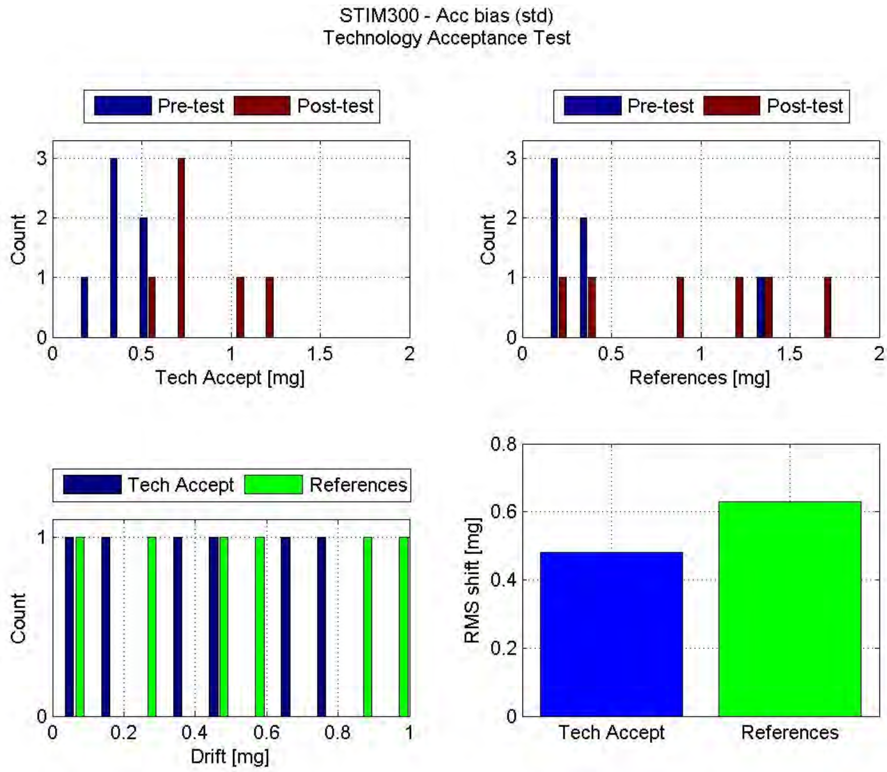


Figure 65 STIM300 Accelerometer bias standard devation over temperature before and after TA test

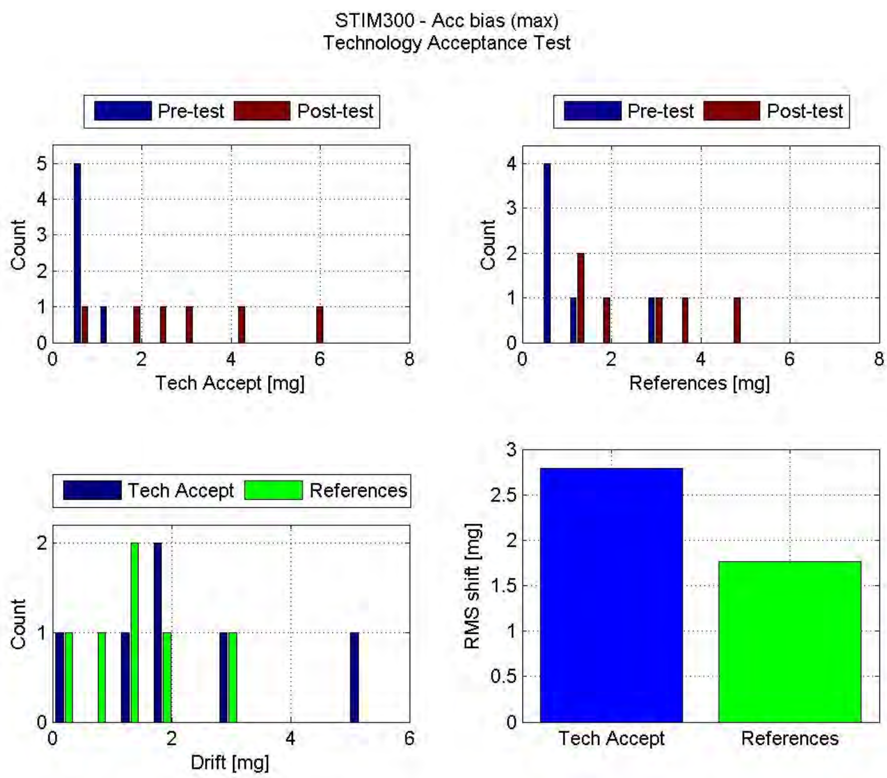


Figure 66 STIM300 Accelerometer Max devation over temperature before and after TA test

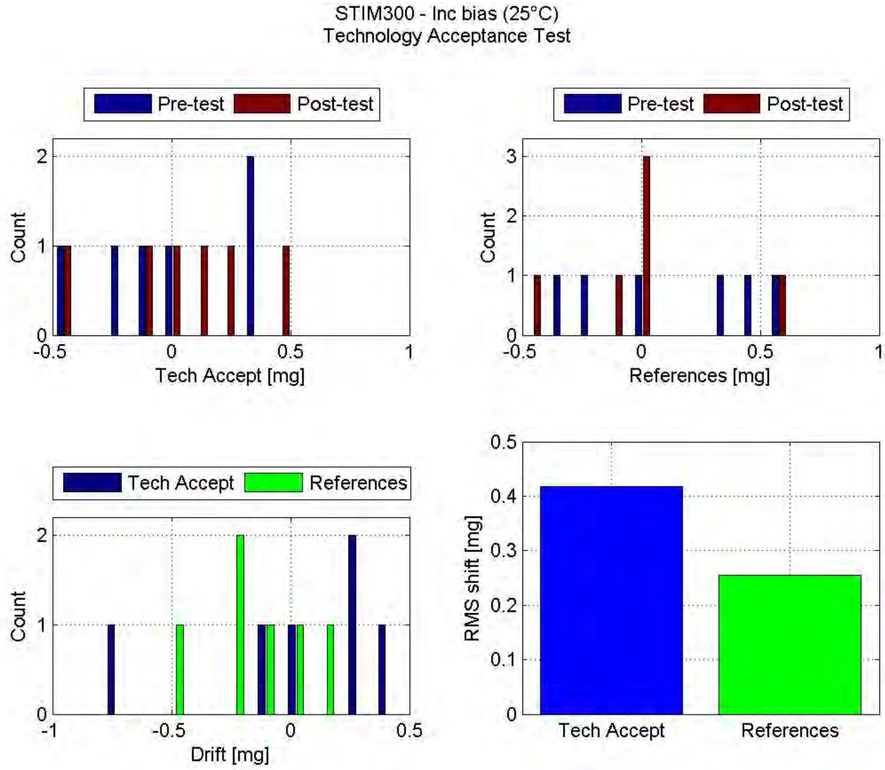


Figure 67 STIM300 inclinometer bias at +25 °C after TA test

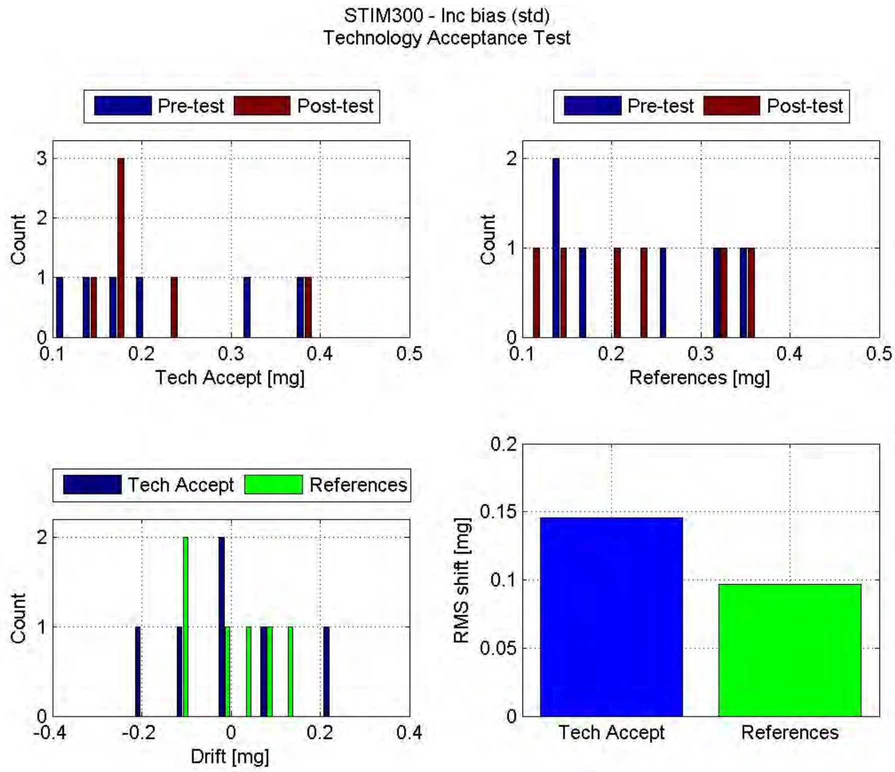


Figure 68 STIM300 Inclinometer bias standard devation over temperature before and after TA test

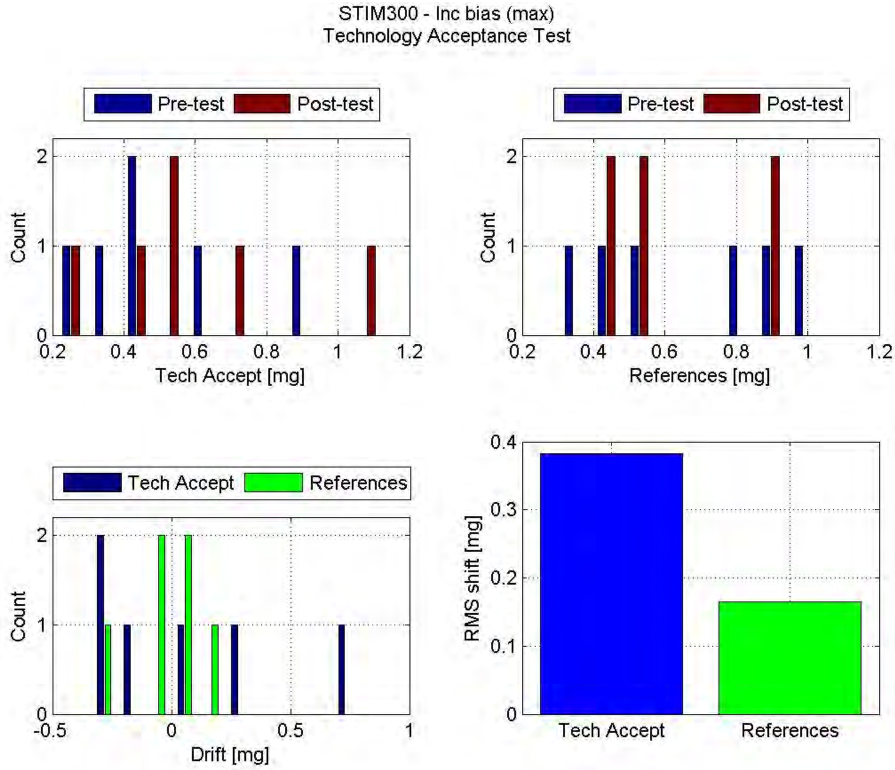


Figure 69 STIM300 Inclinometer bias maximum devation over temperature before and after TA test

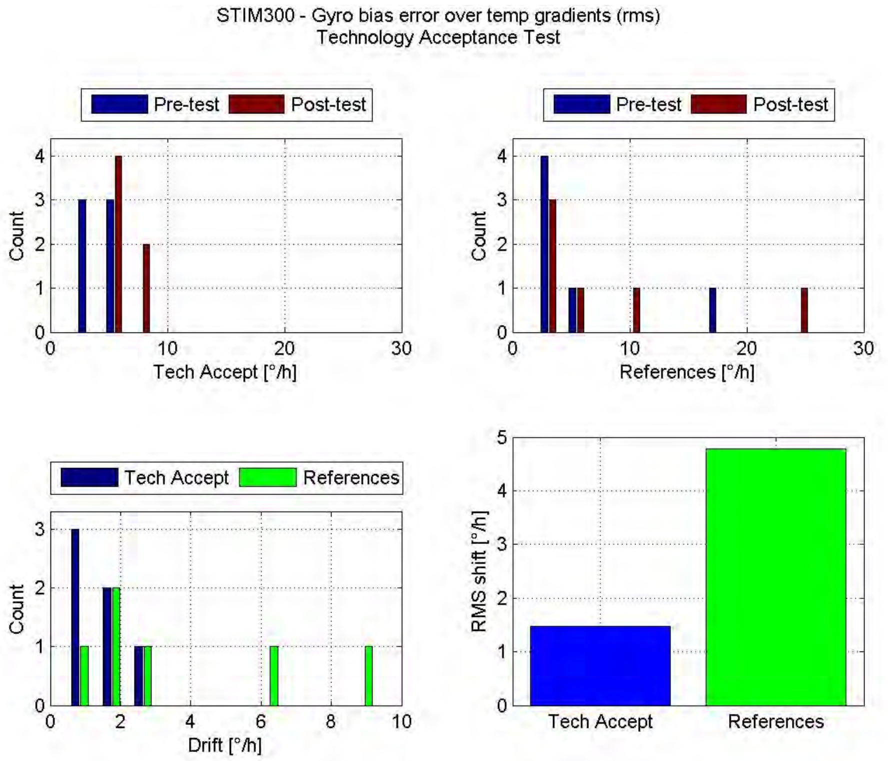


Figure 70 STIM300 Gyro RMS bias error over temperature gradient before and after TA test

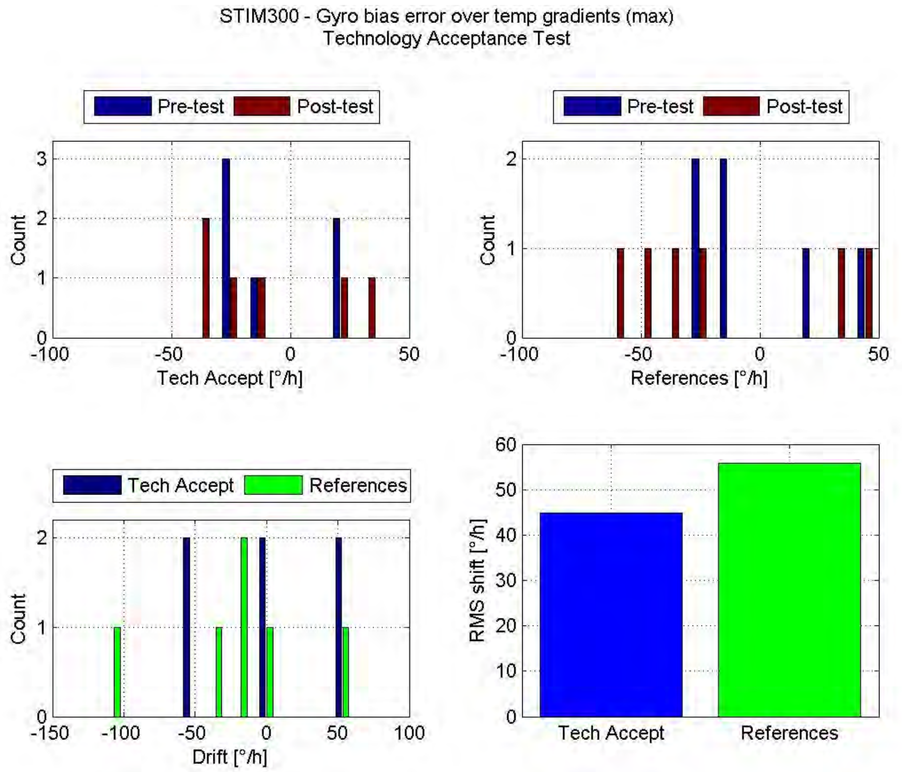


Figure 71 STIM300 Gyro maximum bias error over temperature gradient before and after TA test

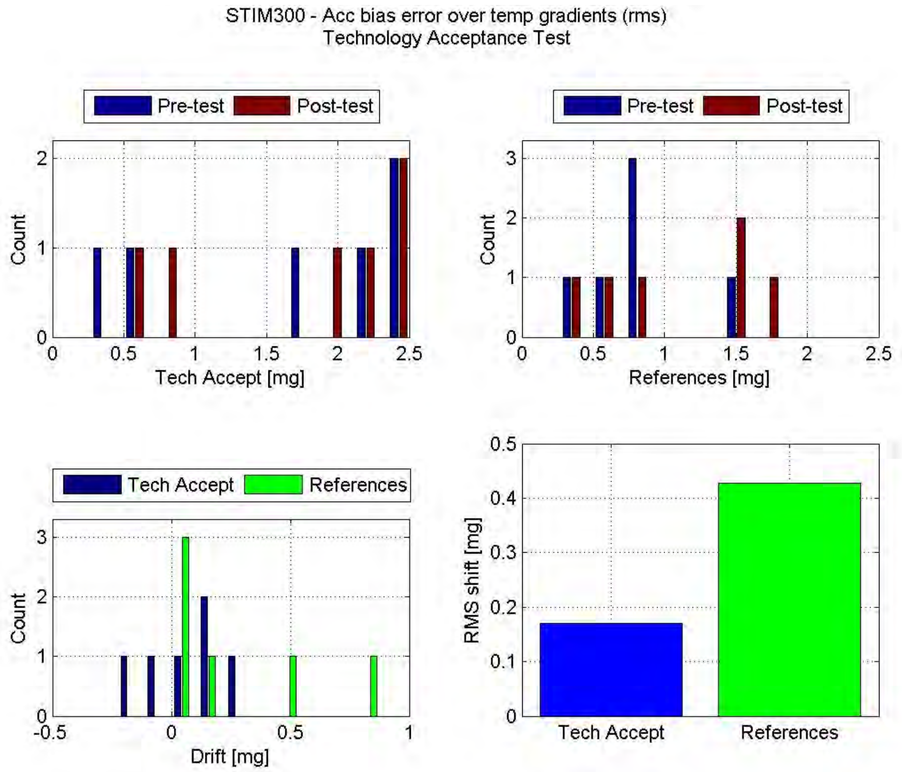


Figure 72 STIM300 Accelerometer RMS bias error over temperature gradient before and after TA test

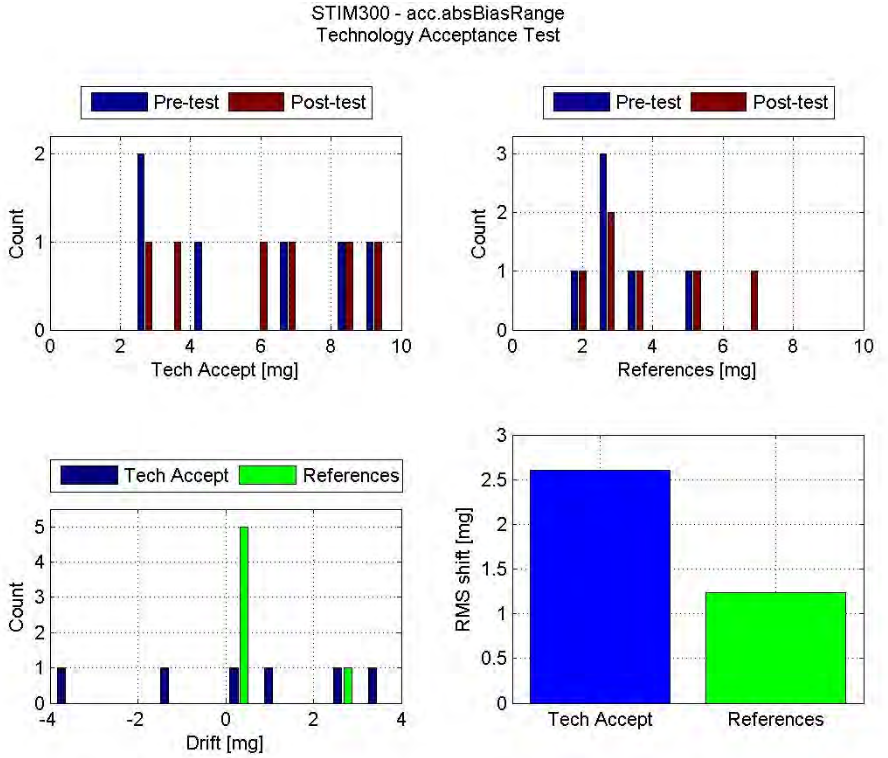


Figure 73 STIM300 Accelerometer bias range over temperature gradient before and after TA test

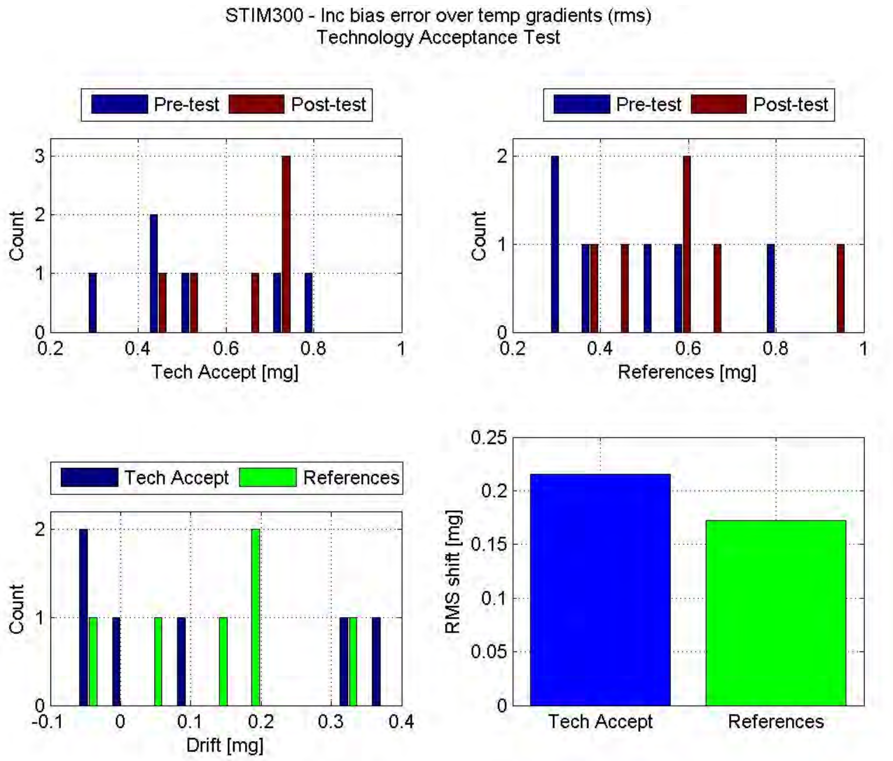


Figure 74 STIM300 Inclinometer RMS bias error over temperature gradient before and after TA test

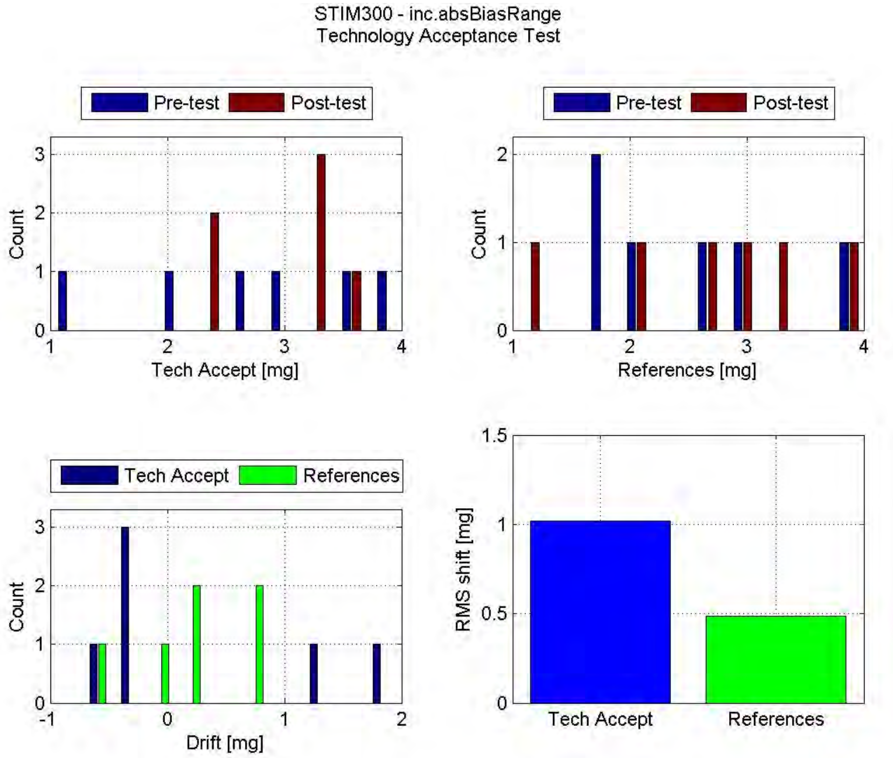


Figure 75 STIM300 Inclinrometer bias range over temperature gradient before and after TA test

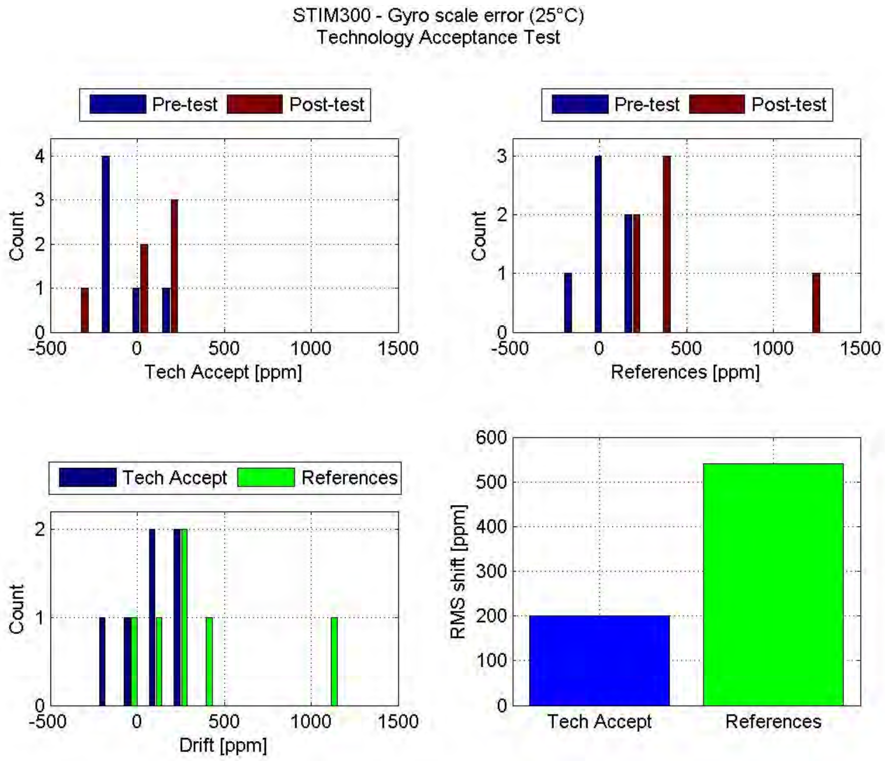


Figure 76 STIM300 Gyro Scale factor error at +25 °C before and after TA test

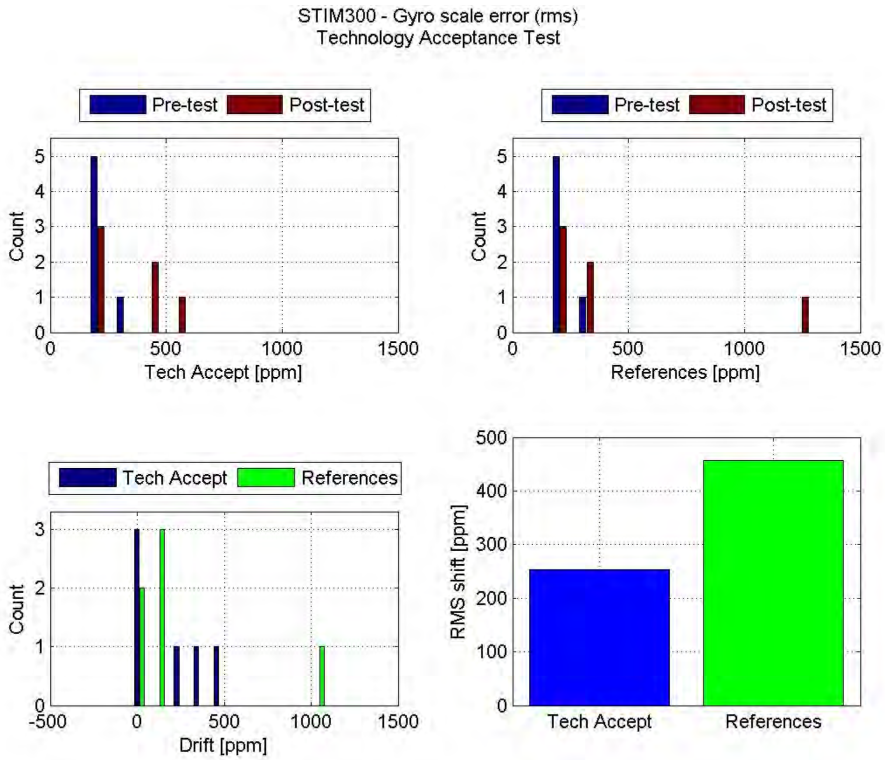


Figure 77 STIM300 Gyro RMS Scale factor error over temperature before and after TA test

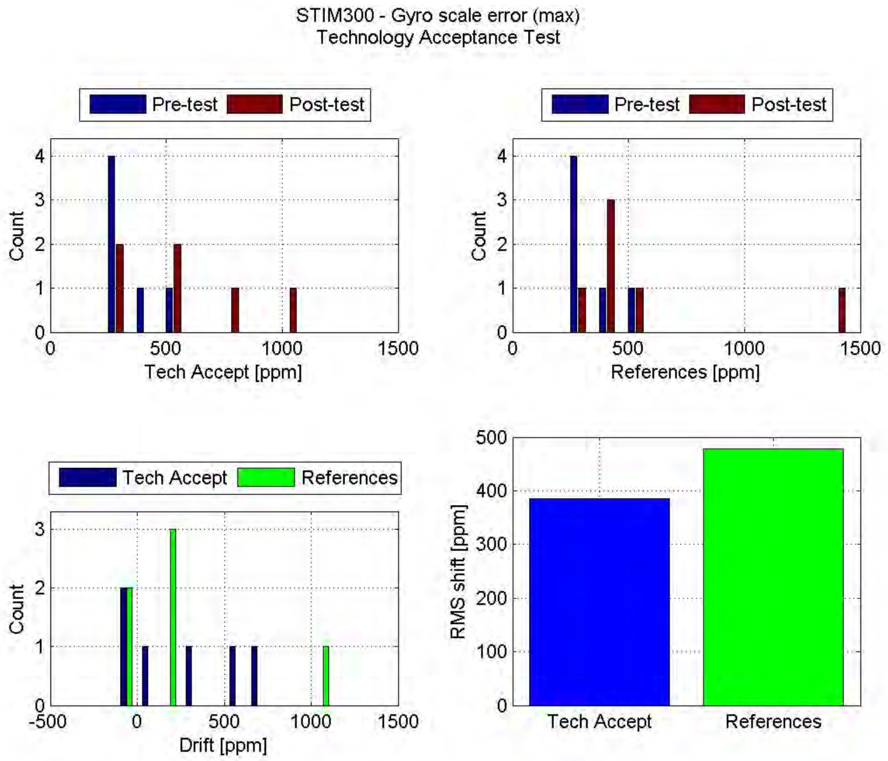


Figure 78 STIM300 Gyro maximum Scale factor error over temperature before and after TA test

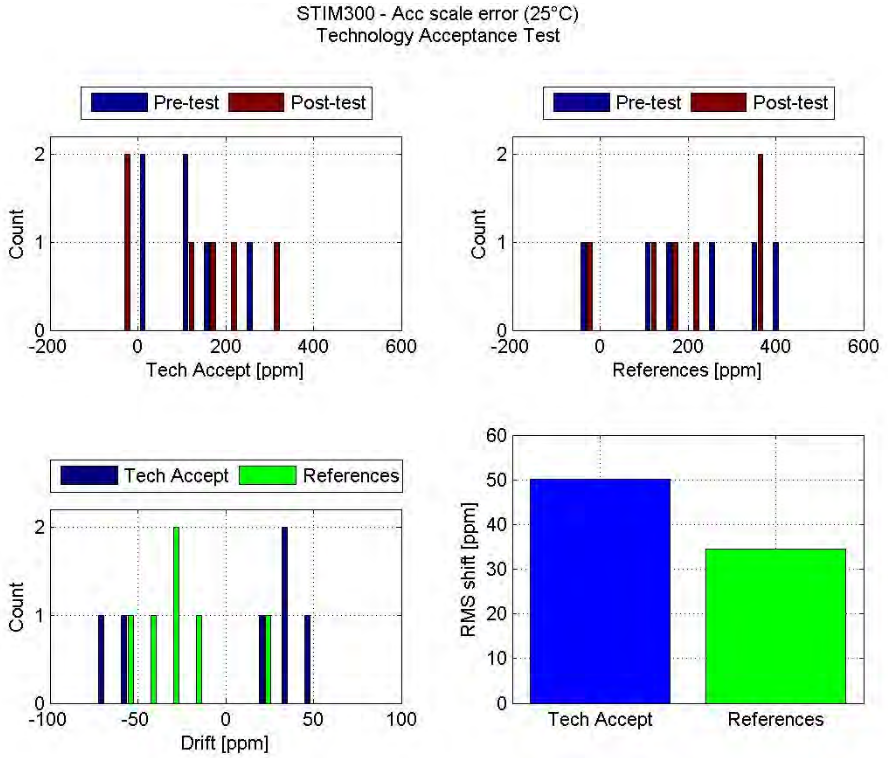


Figure 79 STIM300 Accelerometer Scale factor error at +25 °C before and after TA test

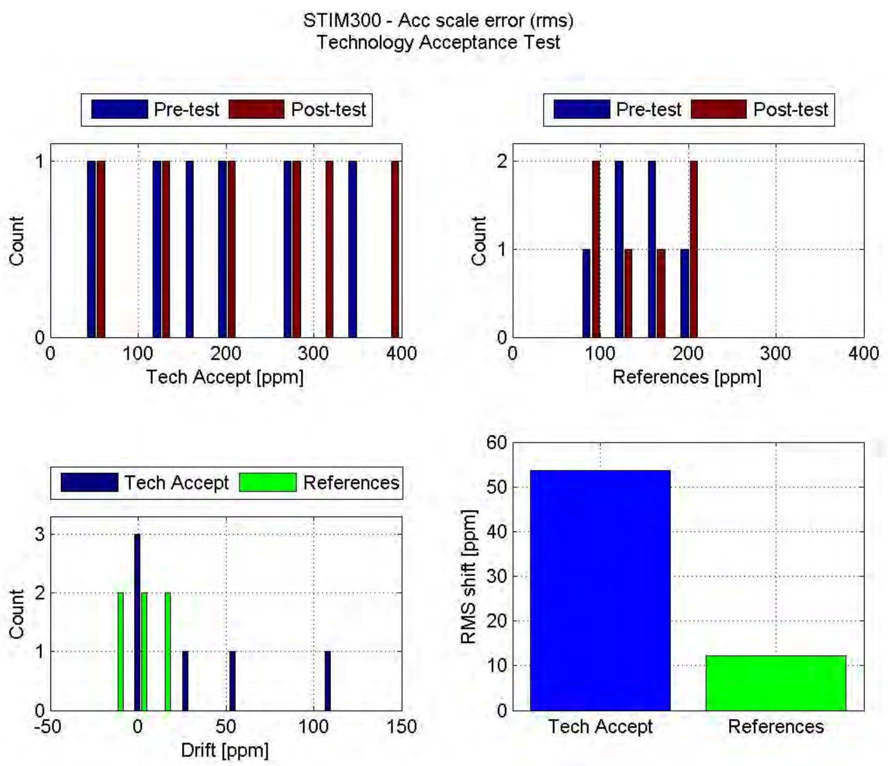


Figure 80 STIM300 Accelerometer RMS Scale factor error over temperature before and after TA test

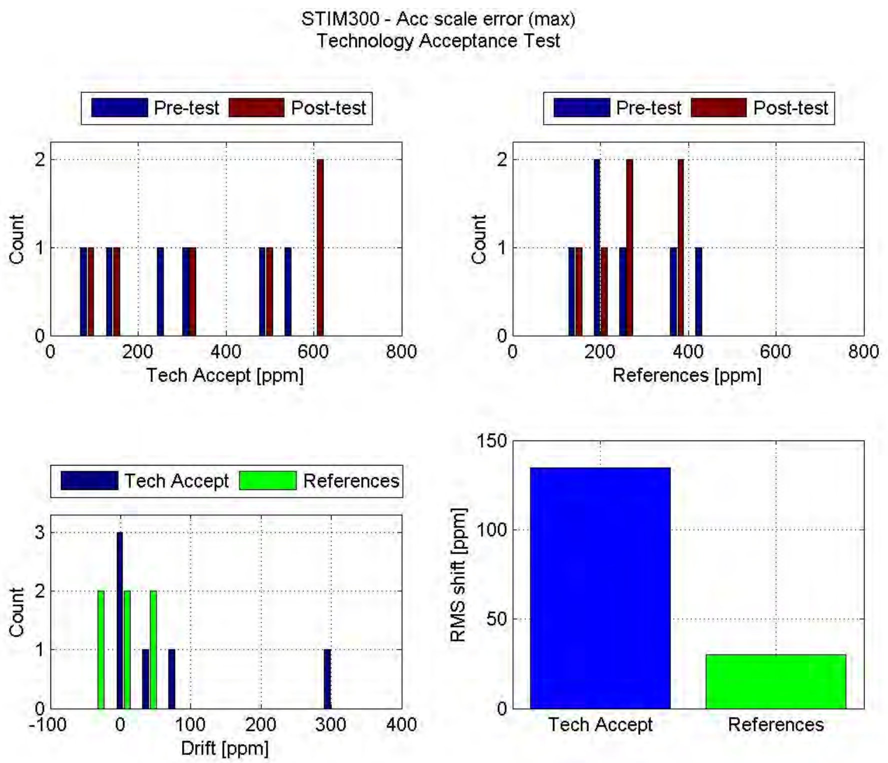


Figure 81 STIM300 Accelerometer maximum Scale factor error over temperature before and after TA test

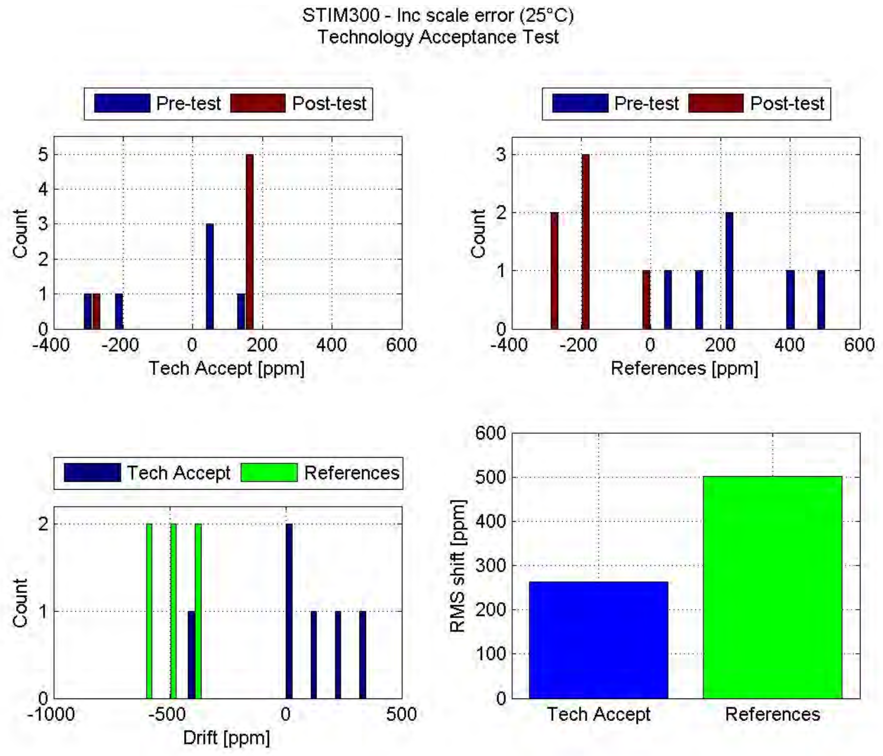


Figure 82 STIM300 Inclinometer Scale factor error at +25 °C before and after TA test

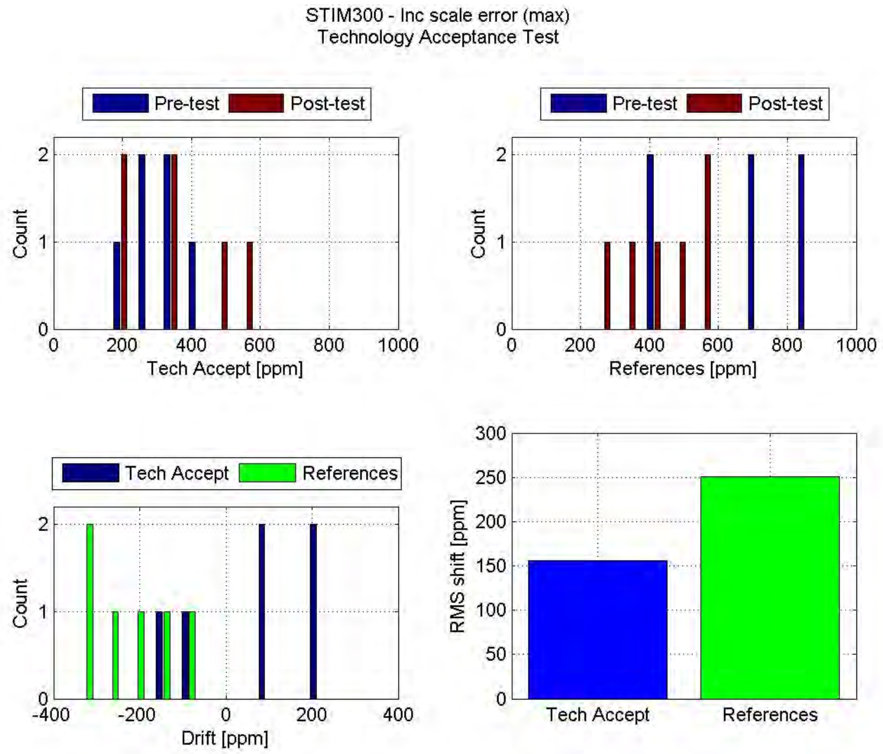


Figure 83 STIM300 Inclinometer maximum Scale factor error over temperature before and after TA test

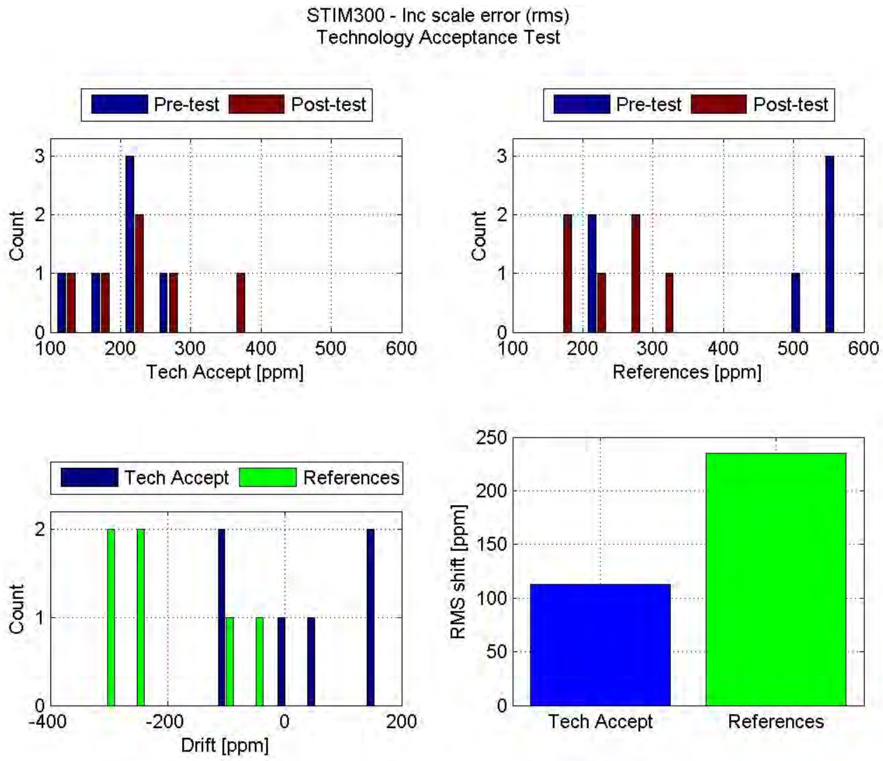


Figure 84 STIM300 Inclinometer RMS Scale factor error over temperature before and after TA test

- **STIM210**

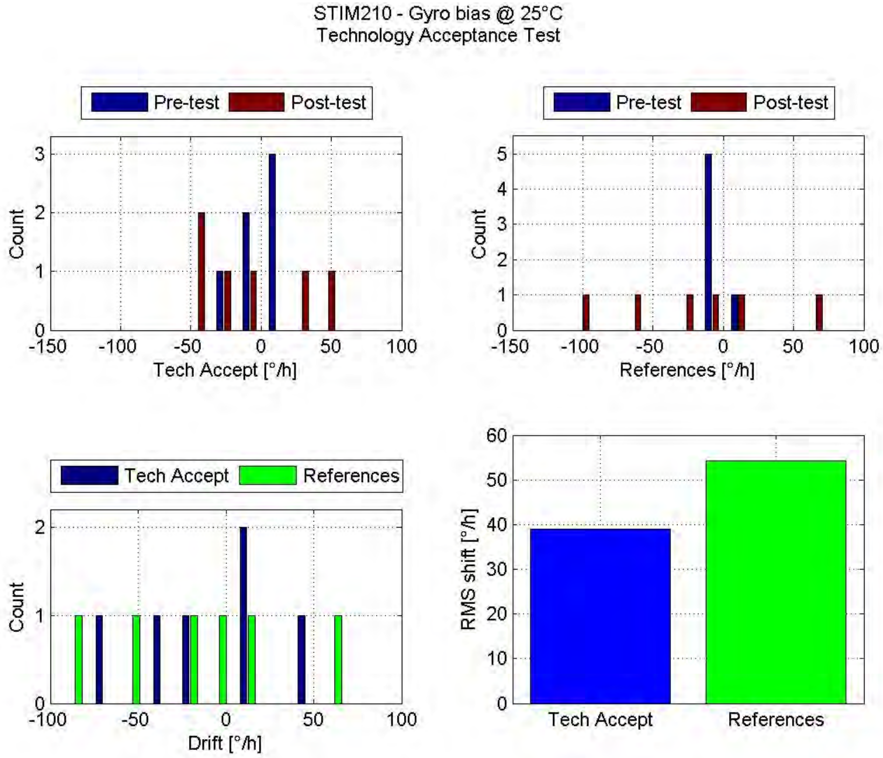


Figure 85 STIM210 Gyro bias error at +25 °C before and after TA test

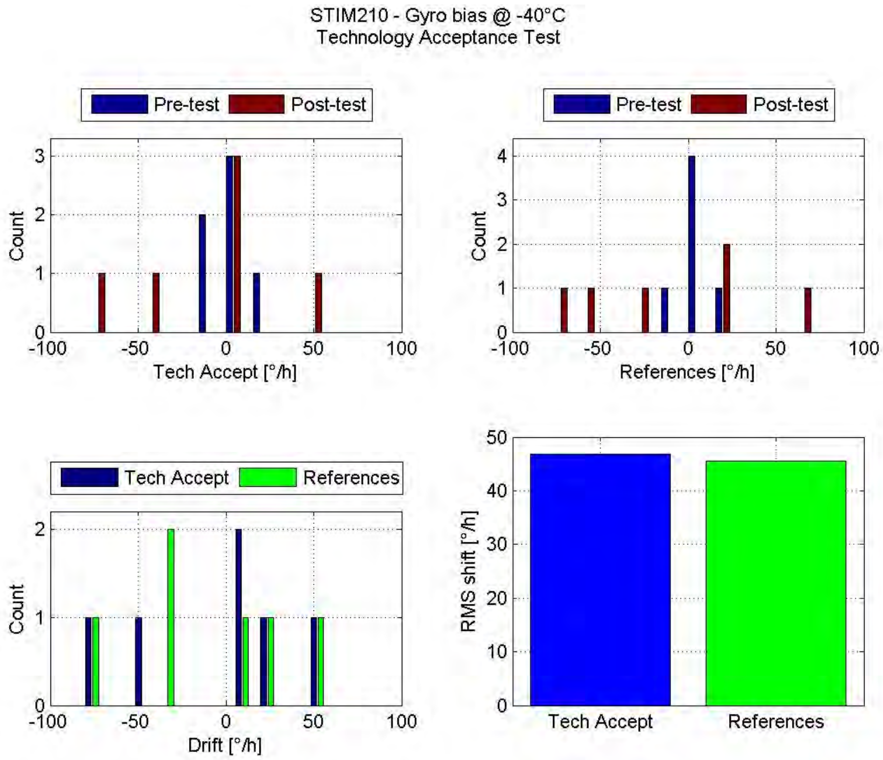


Figure 86 STIM210 Gyro bias error at -40 °C before and after TA test

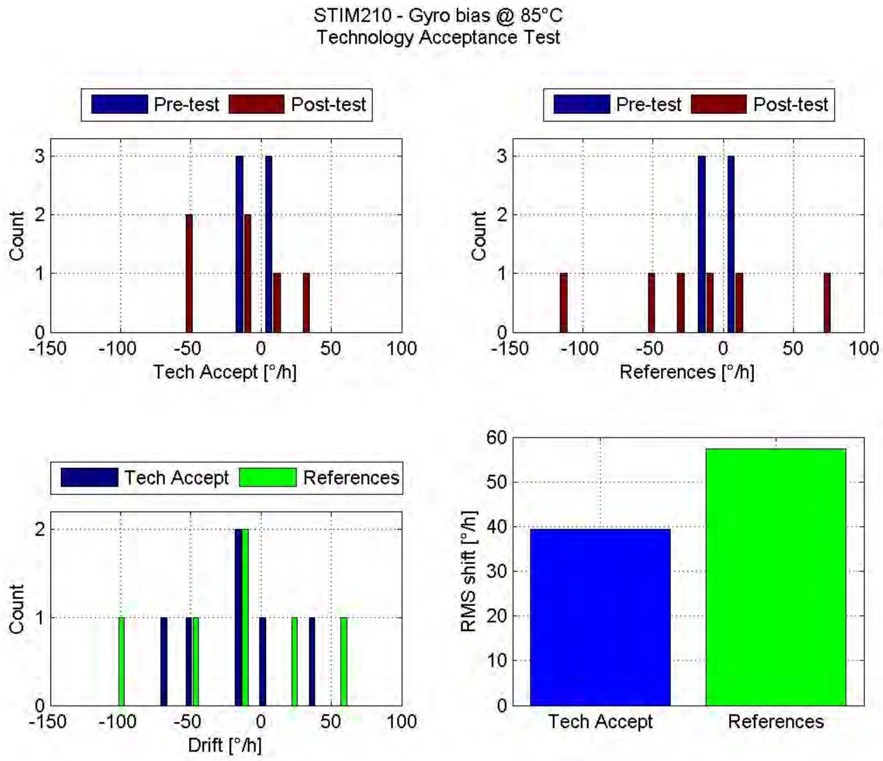


Figure 87 STIM210 Gyro bias error at +85 °C before and after TA test

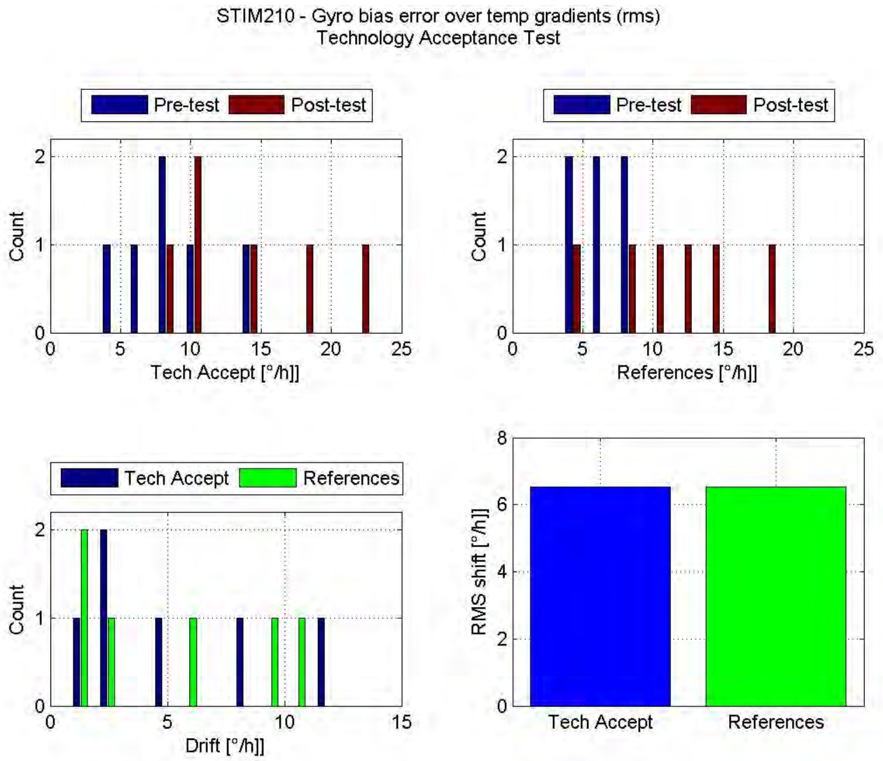


Figure 88 STIM210 Gyro RMS bias error over temperature gradients before and after TA test

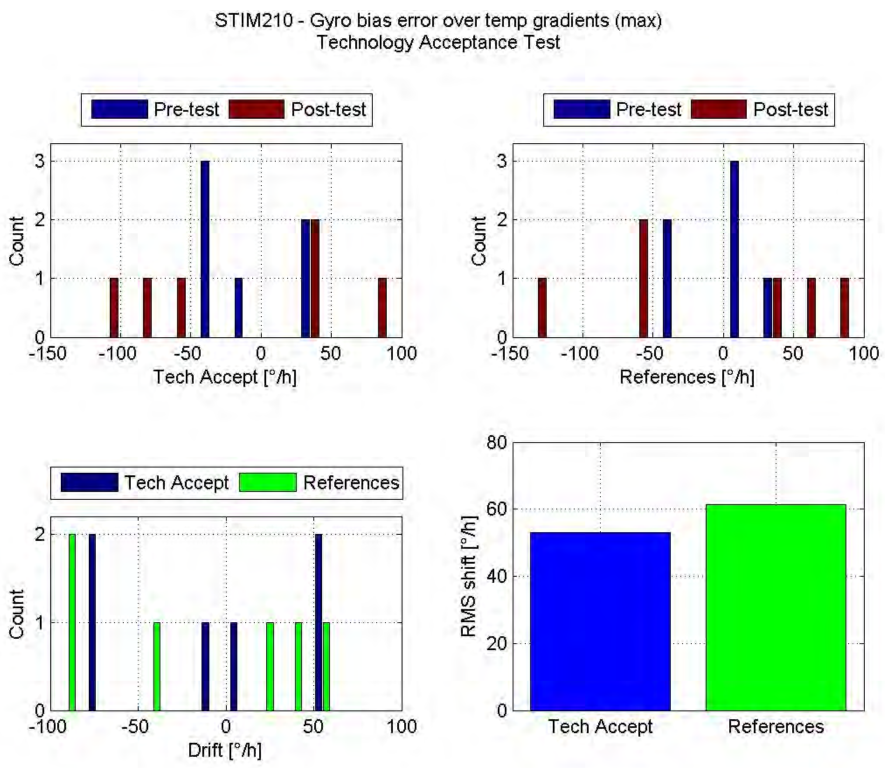


Figure 89 STIM210 Gyro maximum bias error over temperature gradients before and after TA test

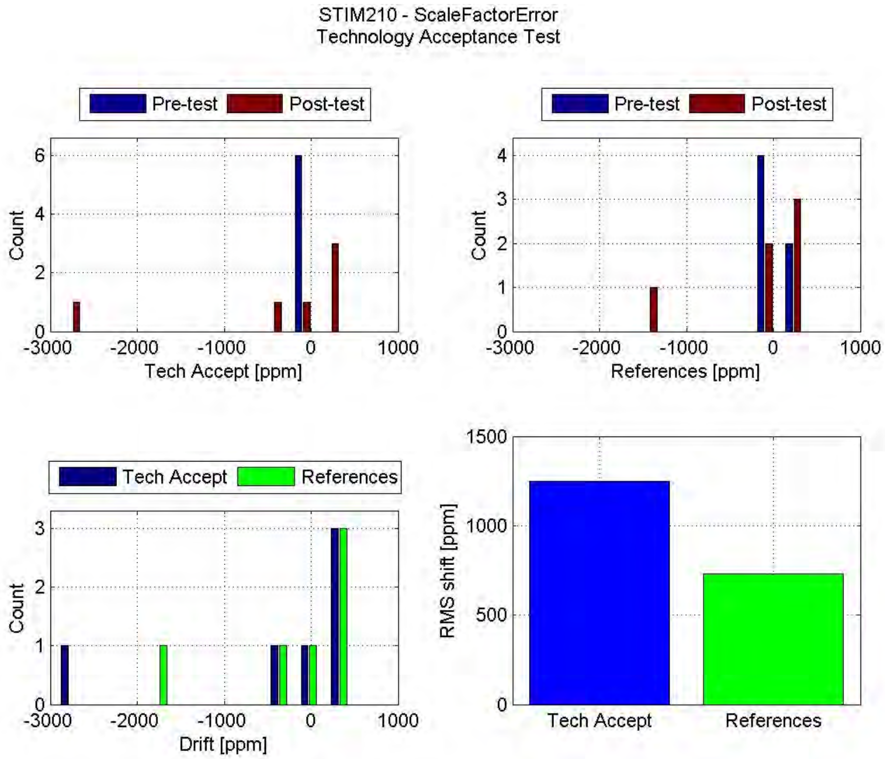


Figure 90 STIM210 Gyro scale factor error over temperature before and after TA test

C Production Test results comparisons before and after TID radiation test

The following figures shows the performance before and after TID radiation test on the key parameters bias shift and scale factor error

- **STIM300**

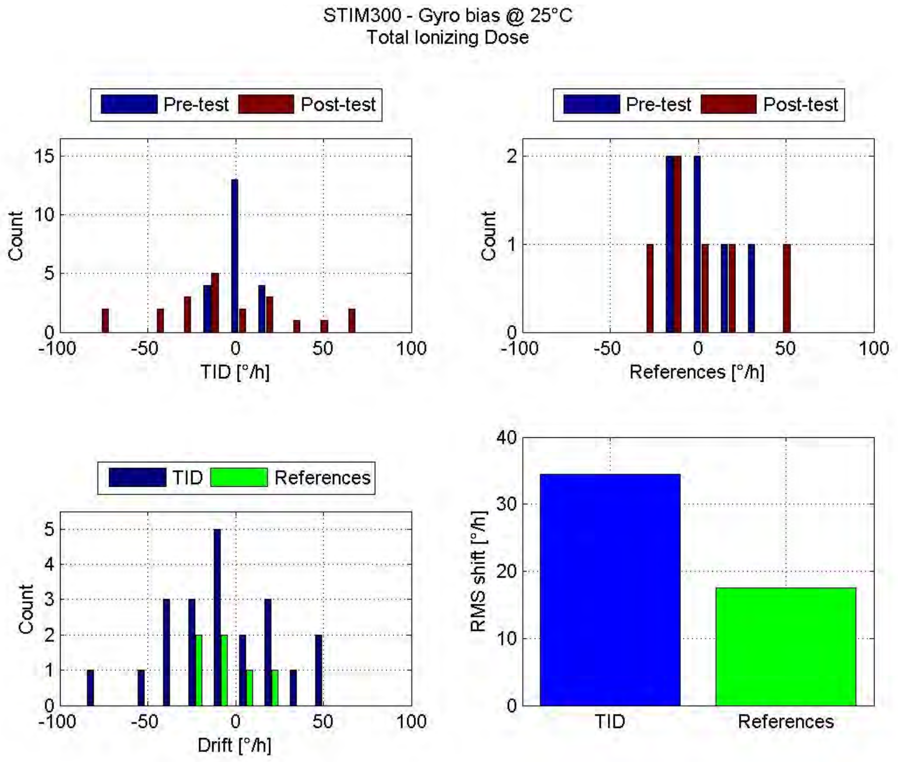


Figure 91 STIM300 Gyro bias error at +25 °C before and after TID test

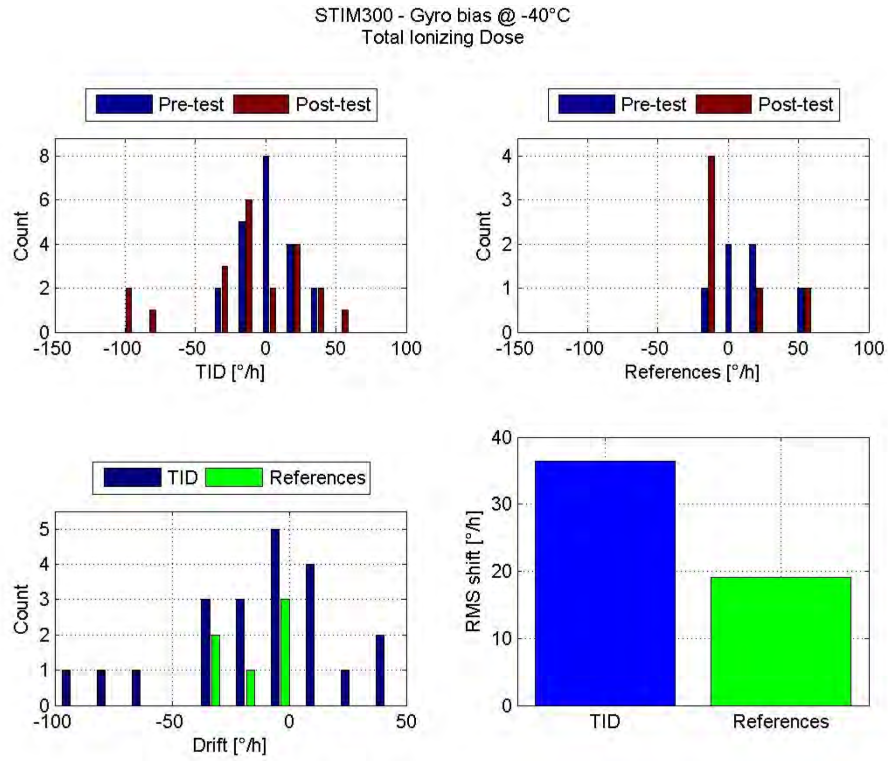


Figure 92 STIM300 Gyro bias error at -40 °C before and after TID test

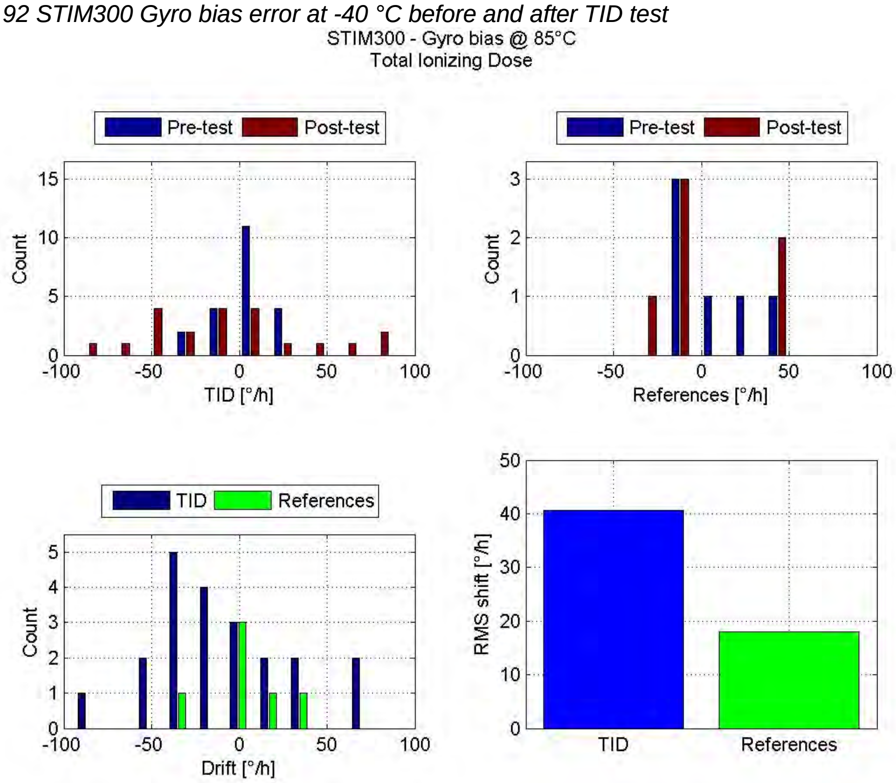


Figure 93 STIM300 Gyro bias error at 85 °C before and after TID test

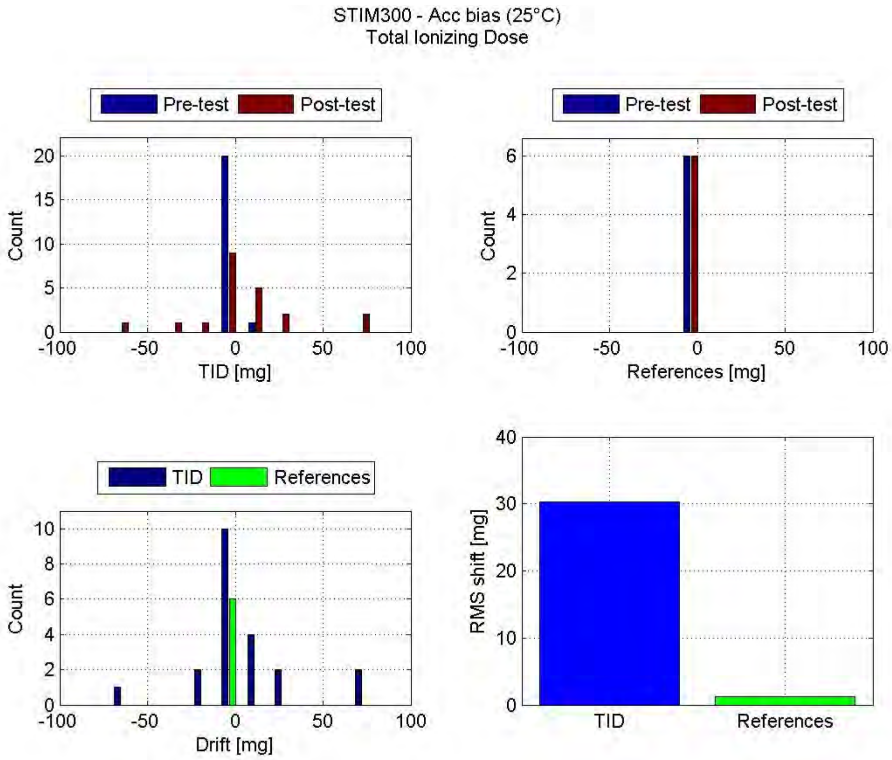


Figure 94 STIM300 Accelerometer bias error at +25 °C before and after TID test

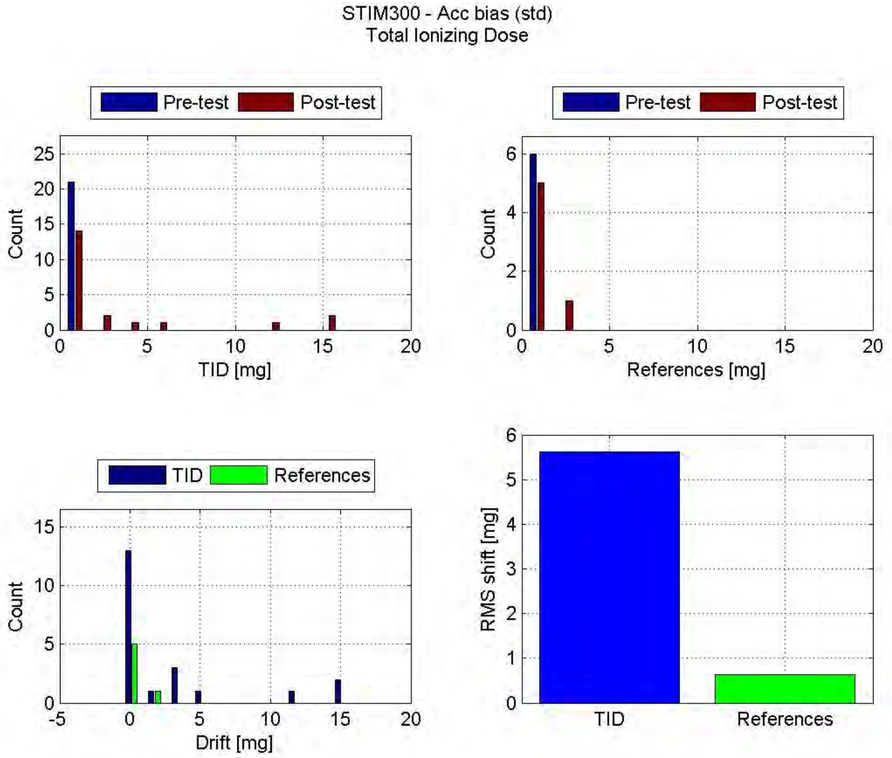


Figure 95 STIM300 Accelerometer RMS bias error over temperature before and after TID test

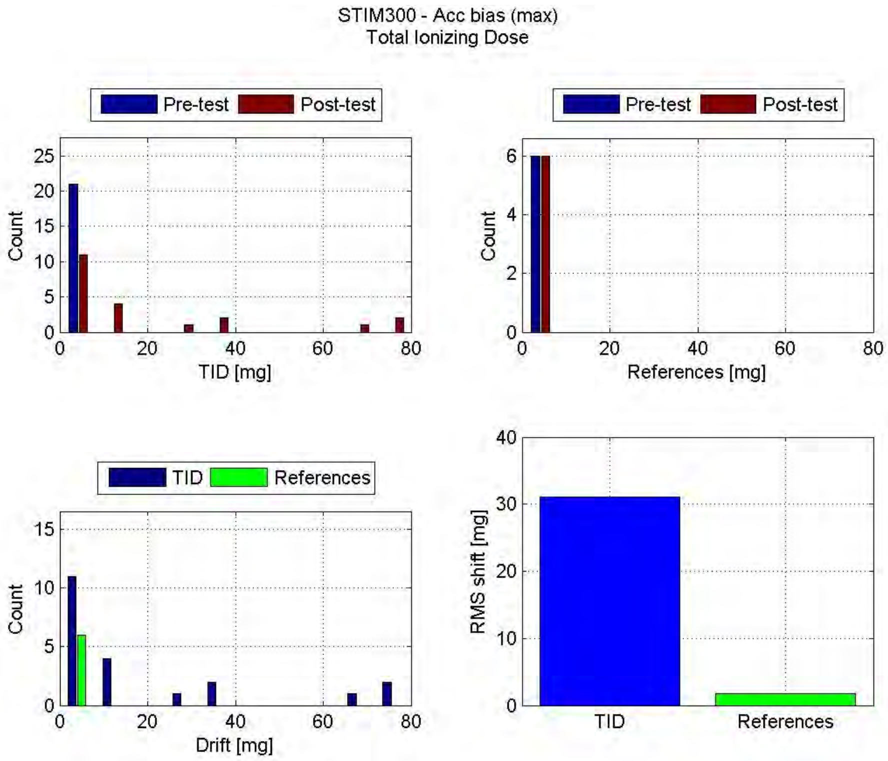


Figure 96 STIM300 Accelerometer maximum bias error over temperature before and after TID test

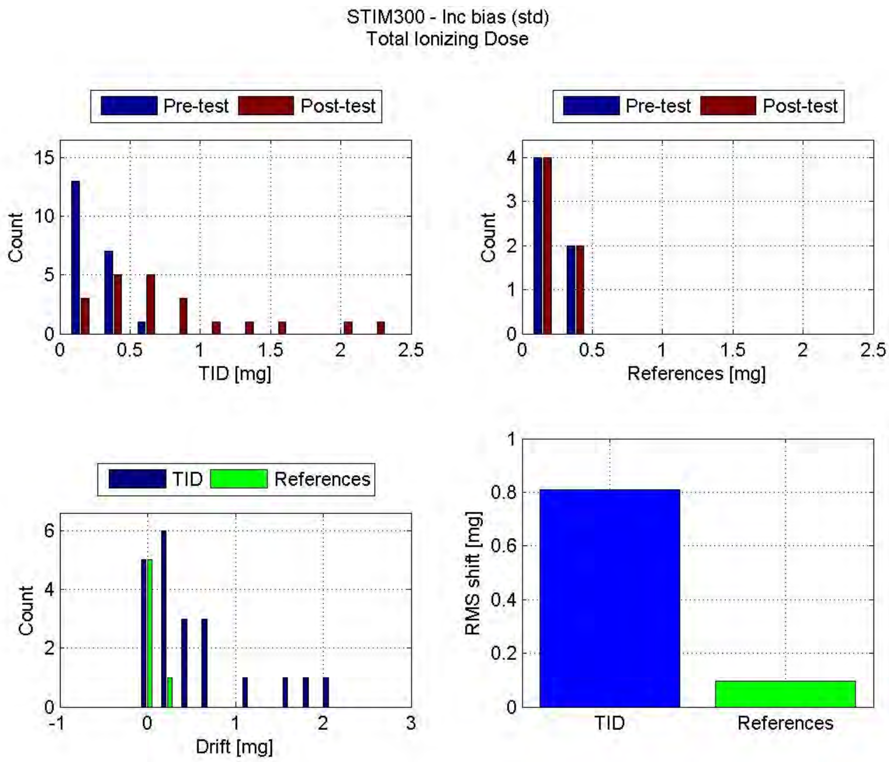


Figure 97 STIM300 Inclinometer RMS bias error over temperature before and after TID test

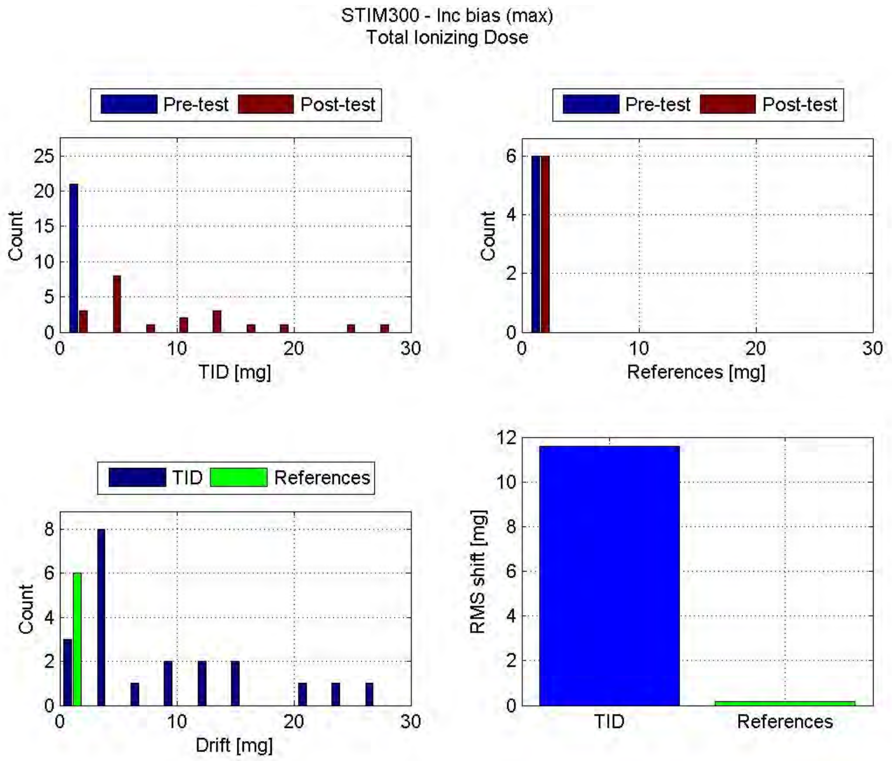


Figure 98 STIM300 Inclinometer maximum bias error over temperature before and after TID test

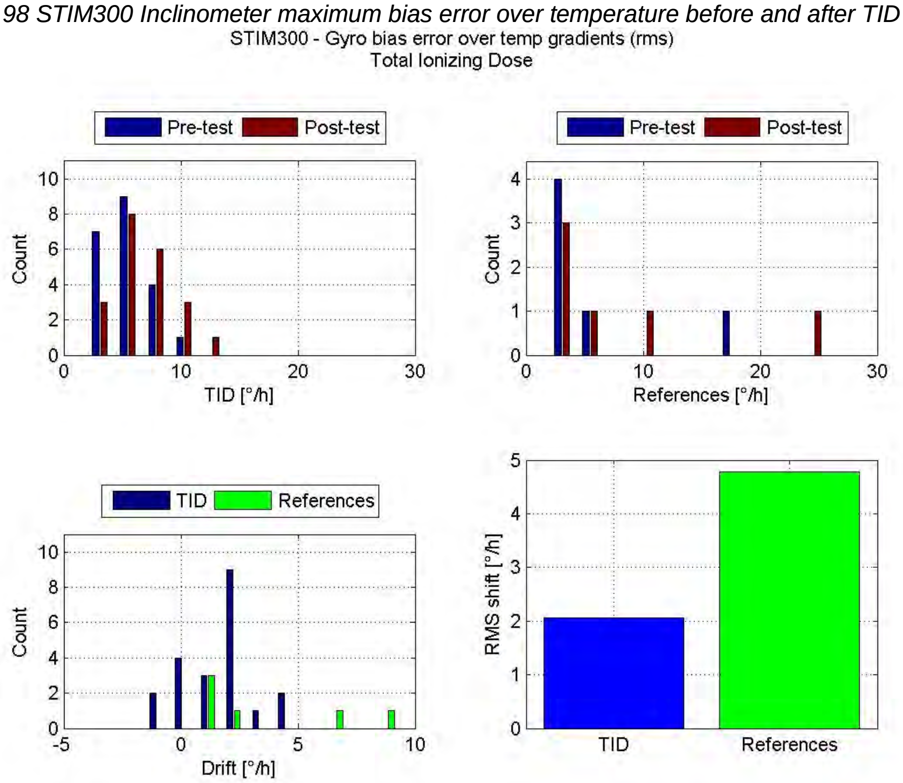


Figure 99 STIM300 Gyro RMS bias error over temperature gradients before and after TID test

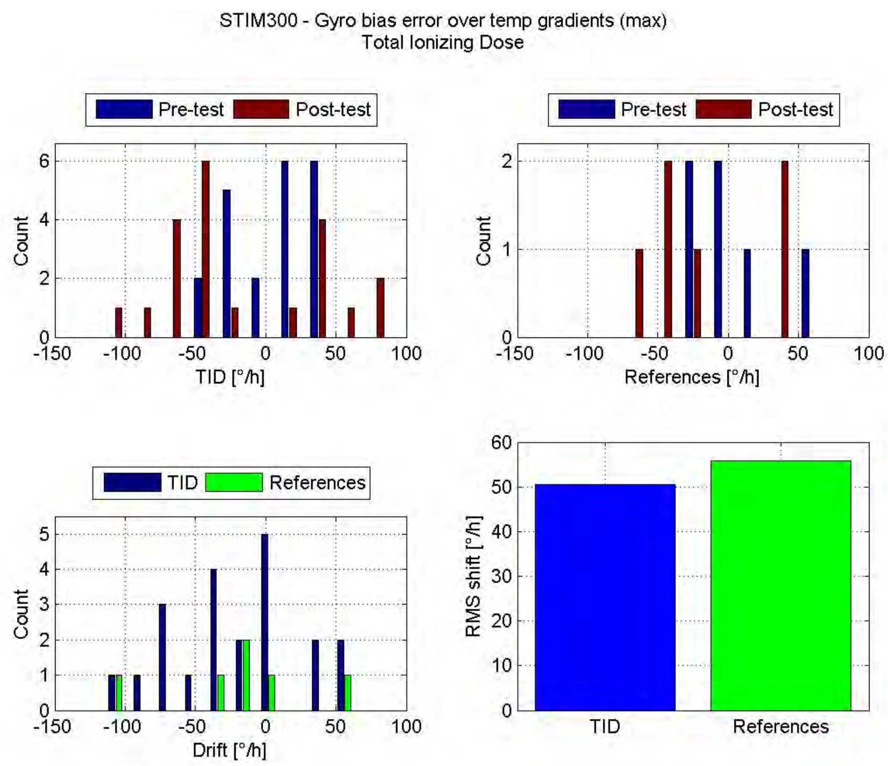


Figure 100 STIM300 Gyro maximum bias error over temperature gradients before and after TID test

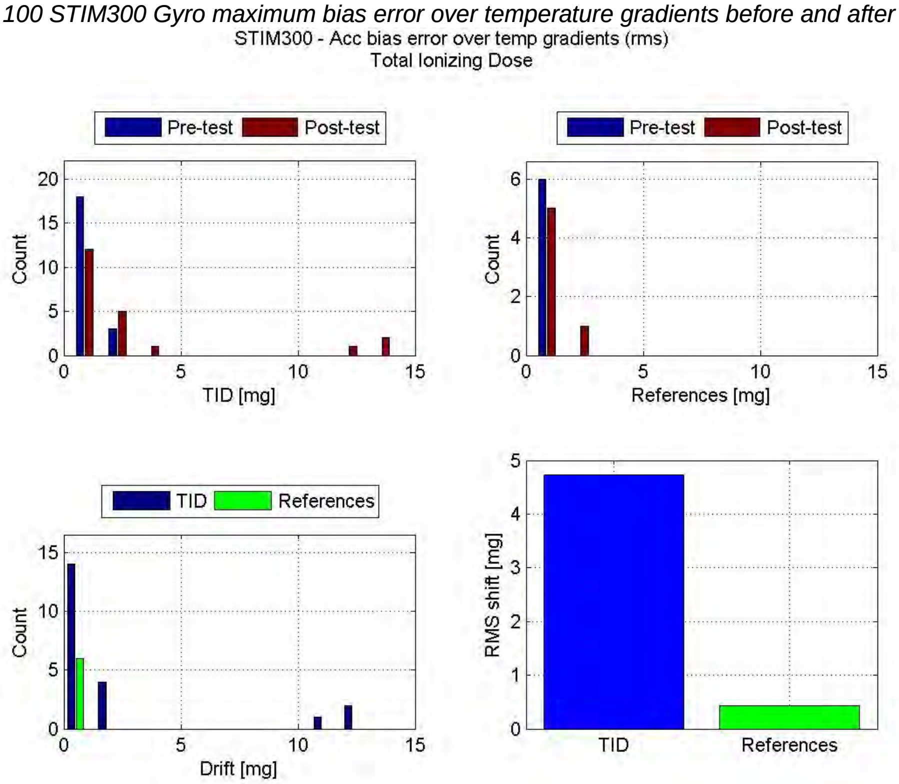


Figure 101 STIM300 Accelerometer RMS bias error over temperature gradients before and after TID test

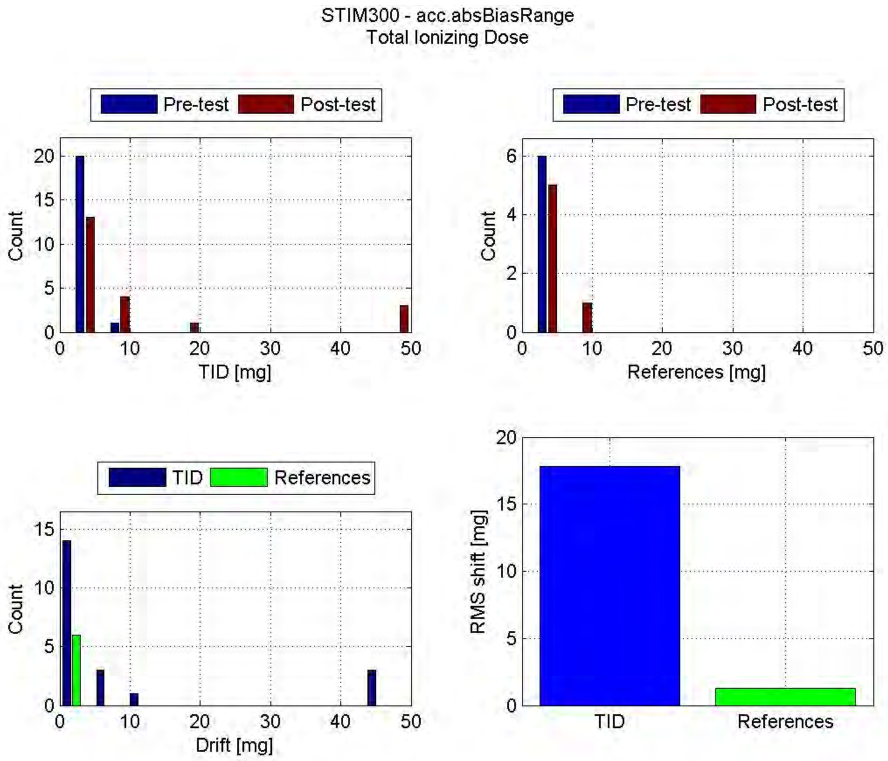


Figure 102 STIM300 Accelerometer maximum bias error over temperature gradients before and after TID test

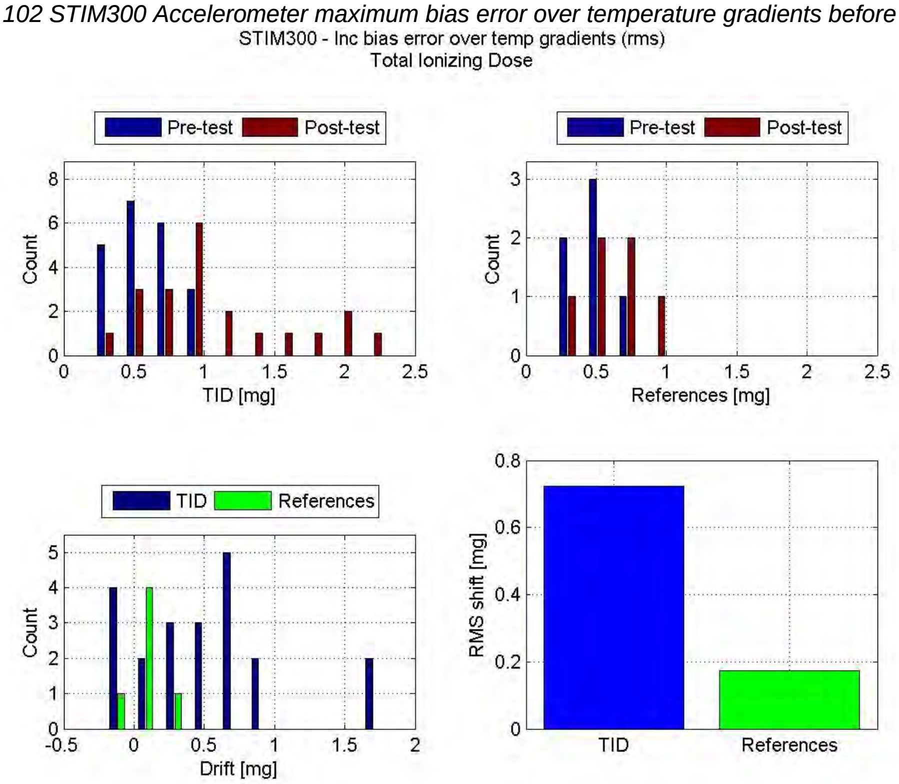


Figure 103 STIM300 Inclinometer RMS bias error over temperature gradients before and after TID test

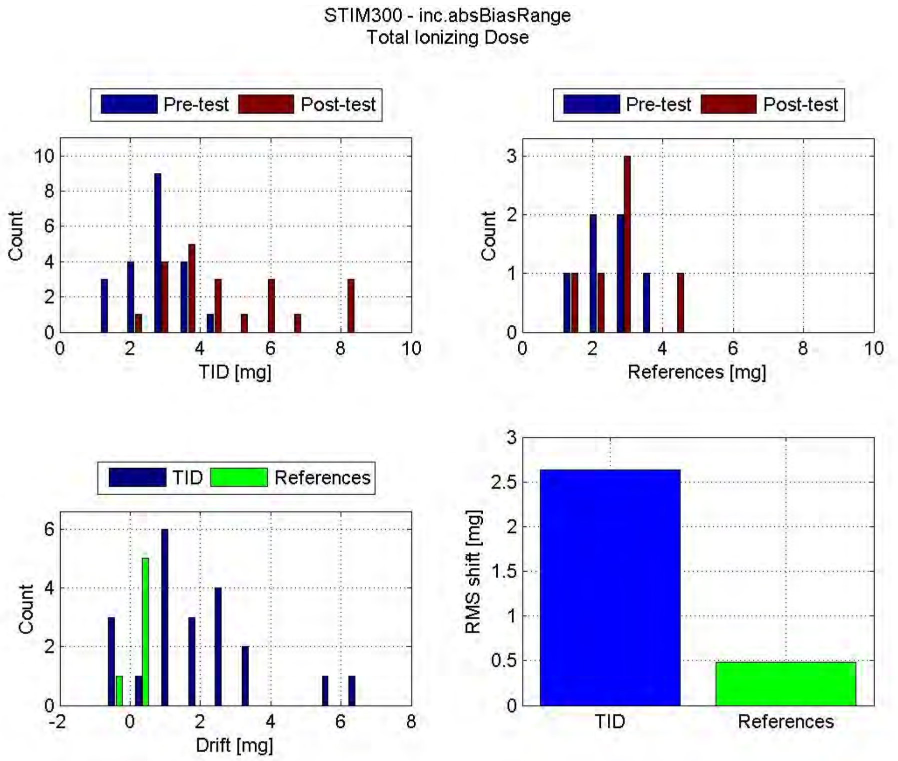


Figure 104 STIM300 Inclinometer maximum bias error over temperature gradients before and after TID test

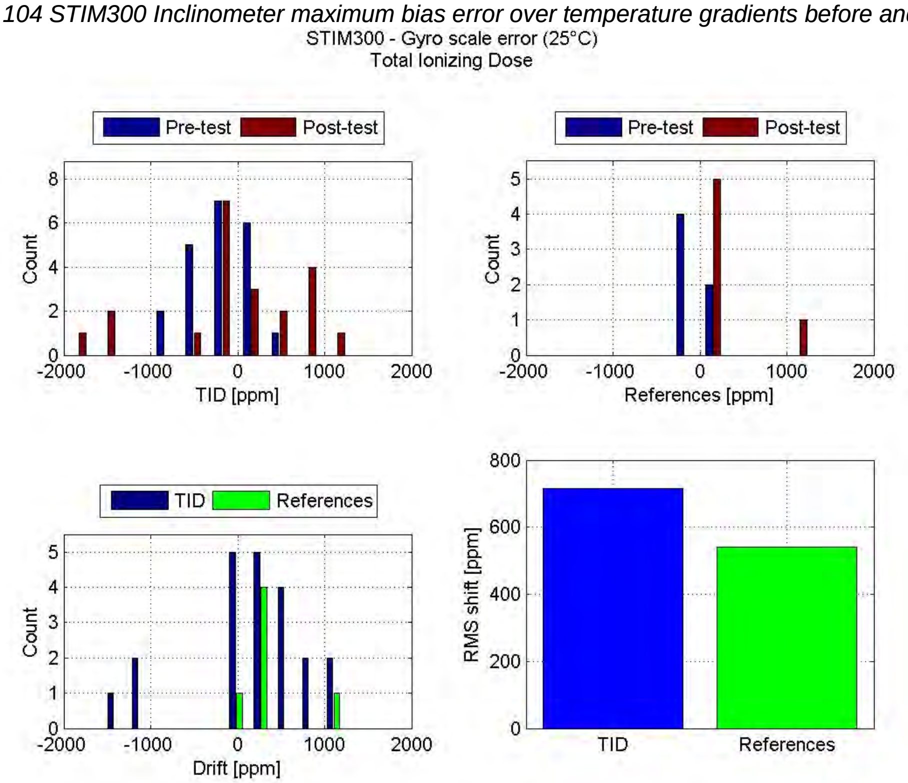


Figure 105 STIM300 Gyro scale factor error at +25 °C before and after TID test

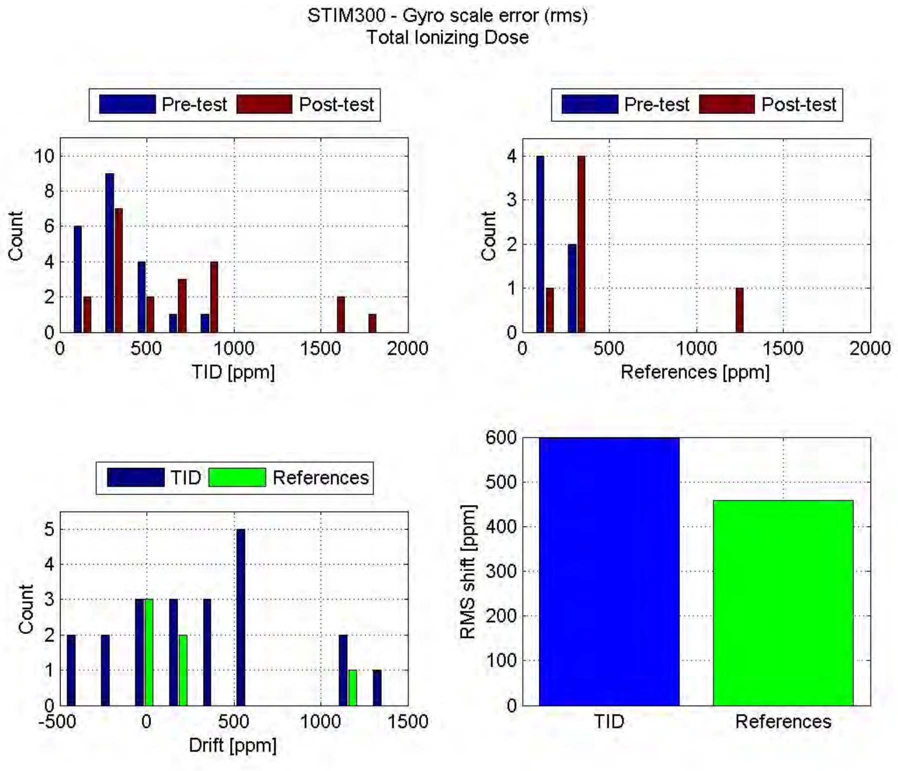


Figure 106 STIM300 Gyro RMS scale factor error over temperature before and after TID test

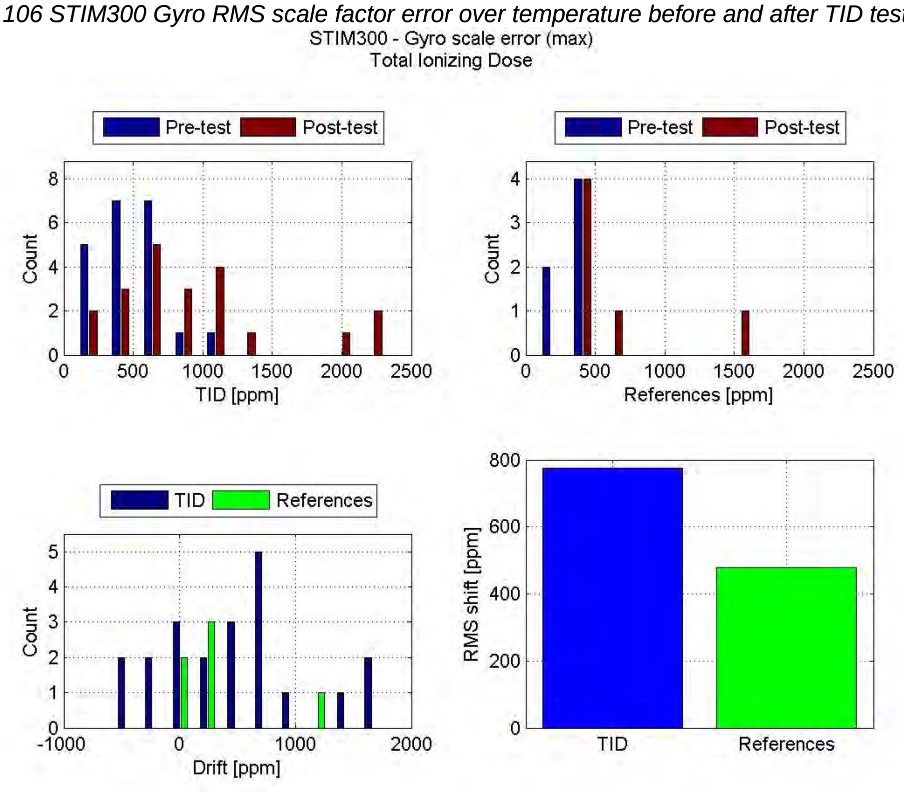


Figure 107 STIM300 Gyro maximum scale factor error over temperature before and after TID test

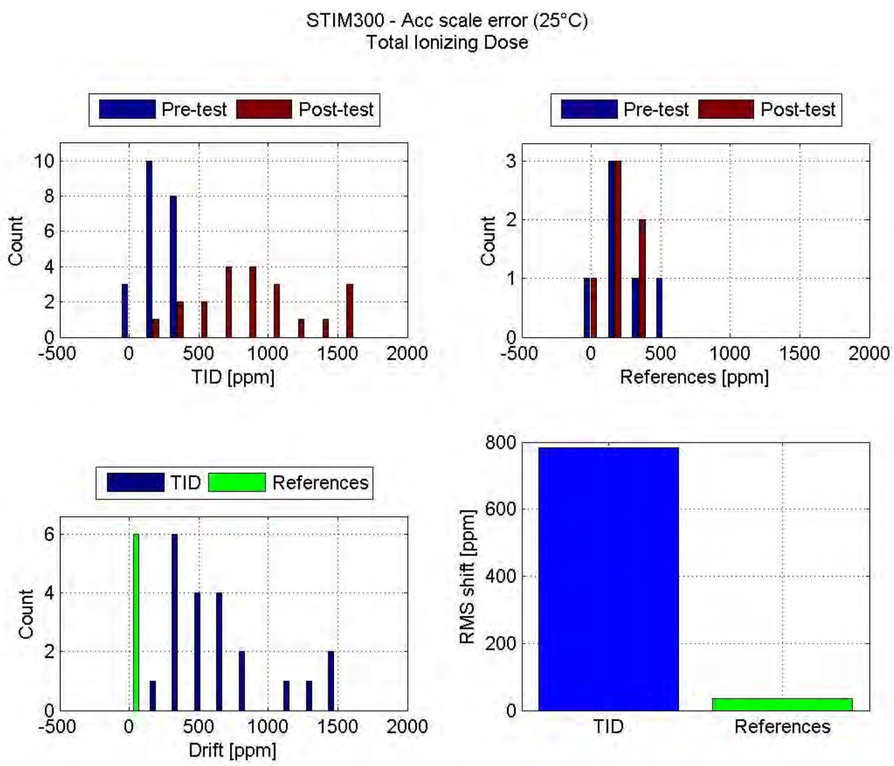


Figure 108 STIM300 Accelerometer scale factor error at +25 °C before and after TID test

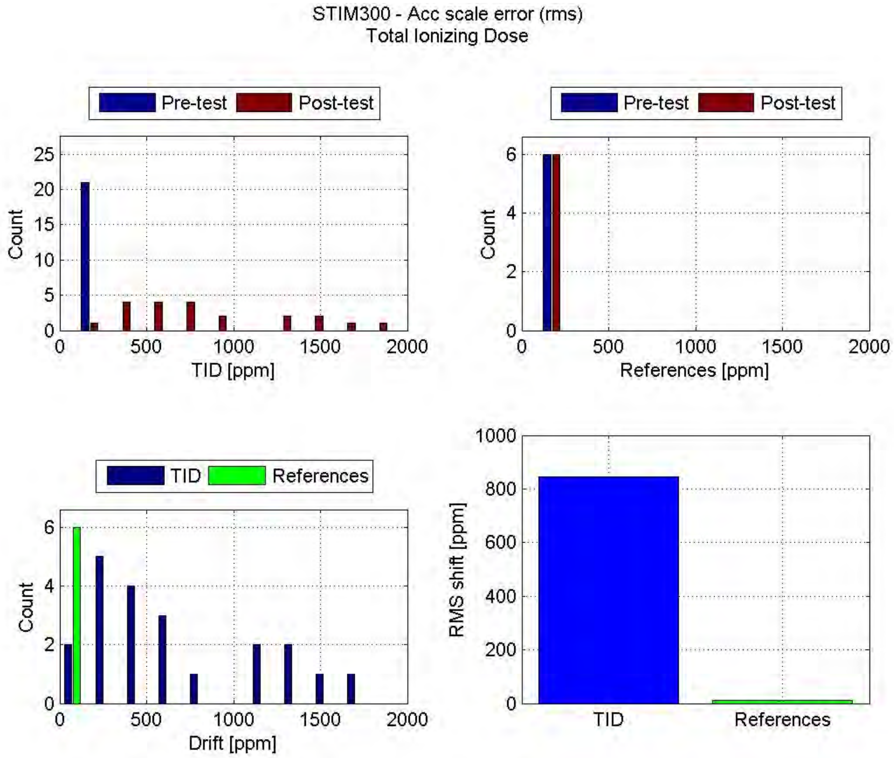


Figure 109 STIM300 Accelerometer RMS scale factor error over temperature before and after TID test

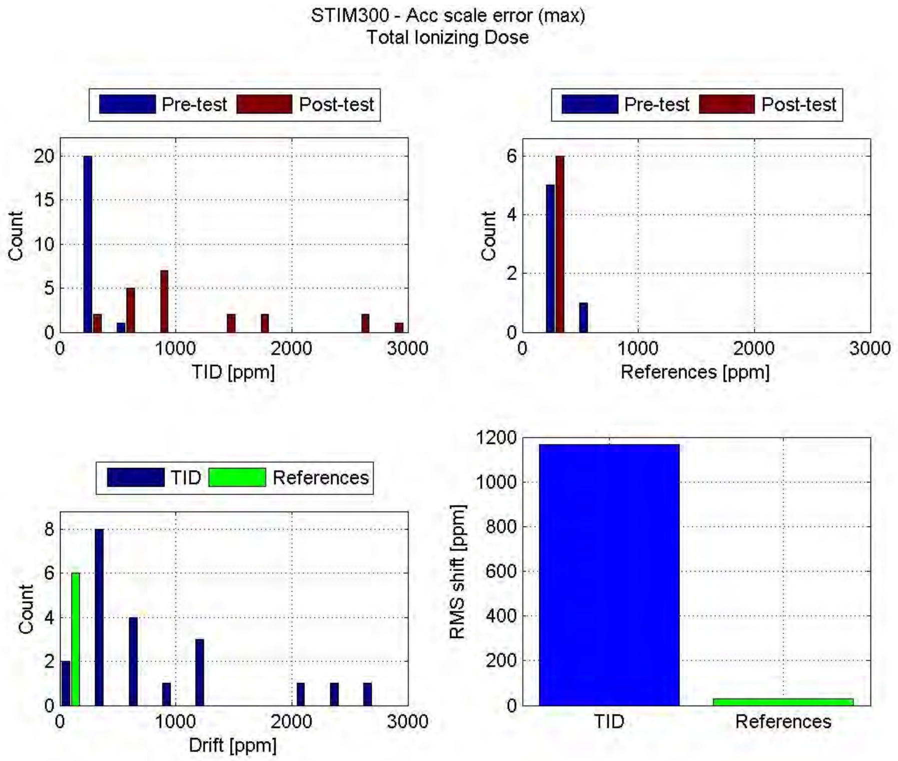


Figure 110 STIM300 Accelerometer maximum scale factor error over temperature before and after TID test

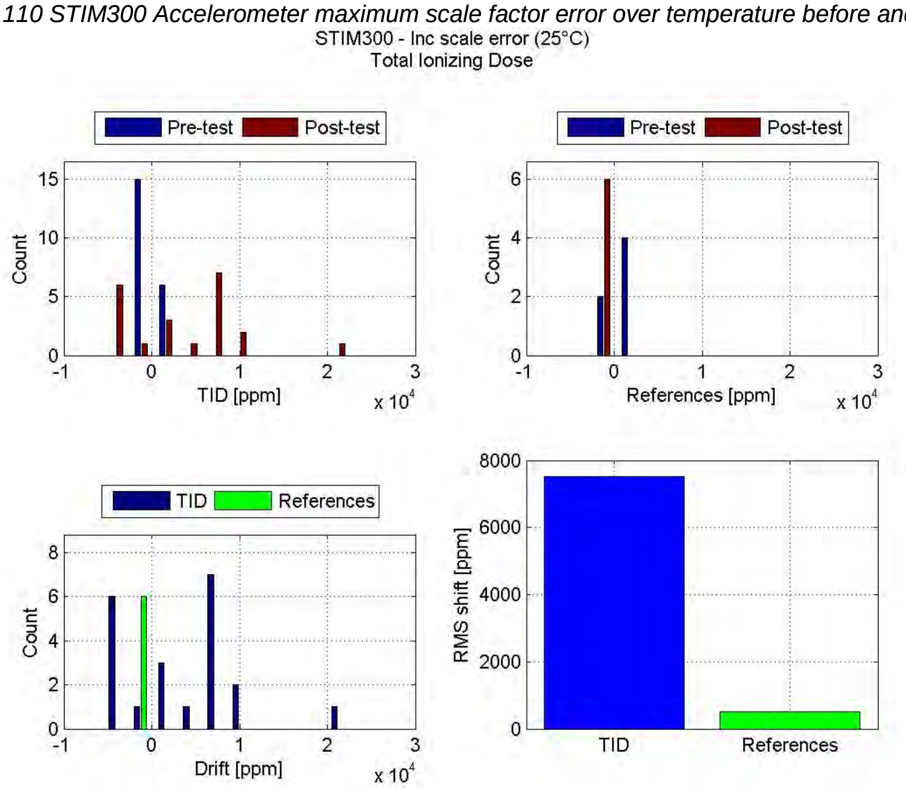


Figure 111 STIM300 Inclinometer scale factor error at +25 °C before and after TID test

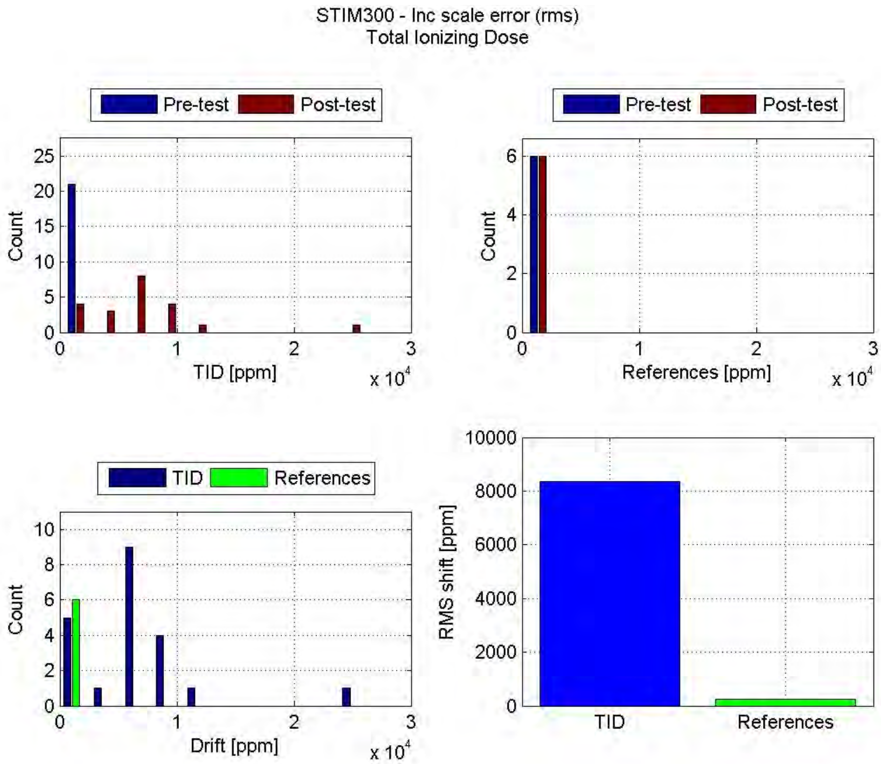


Figure 112 STIM300 Inclinometer RMS scale factor error over temperature before and after TID test

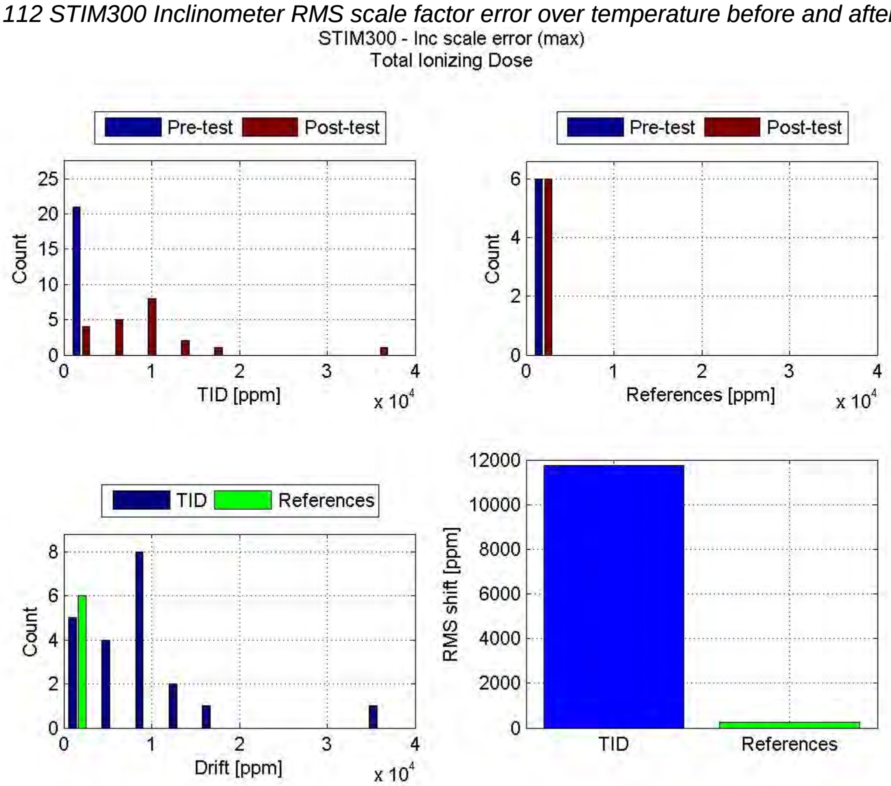


Figure 113 STIM300 Inclinometer maximum scale factor error over temperature before and after TID test

- **STIM210**

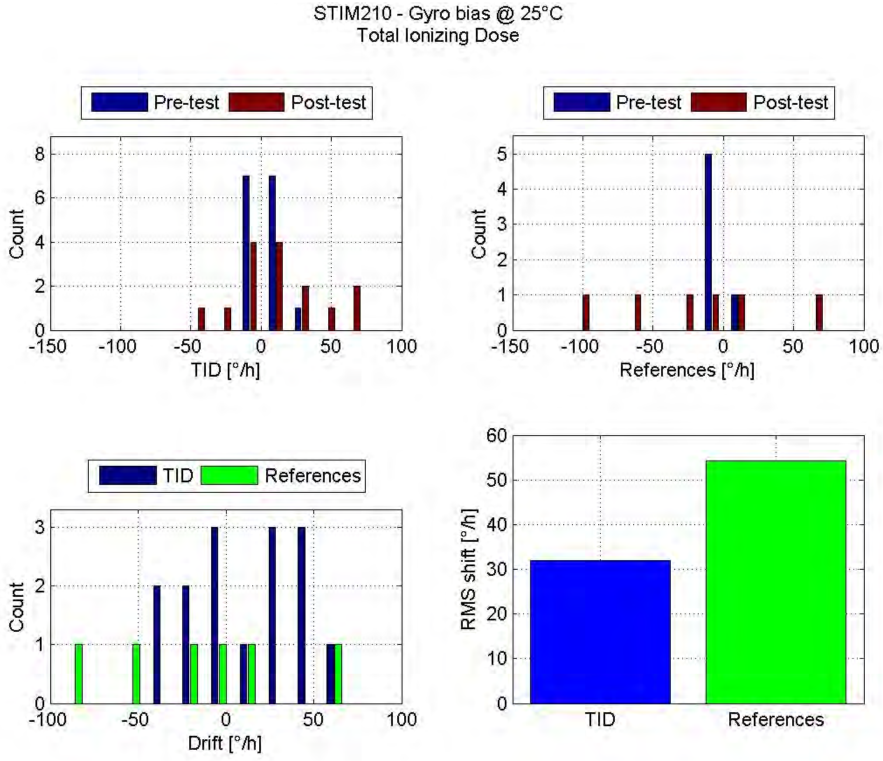


Figure 114 STIM210 Gyro bias error at +25 °C before and after TID test

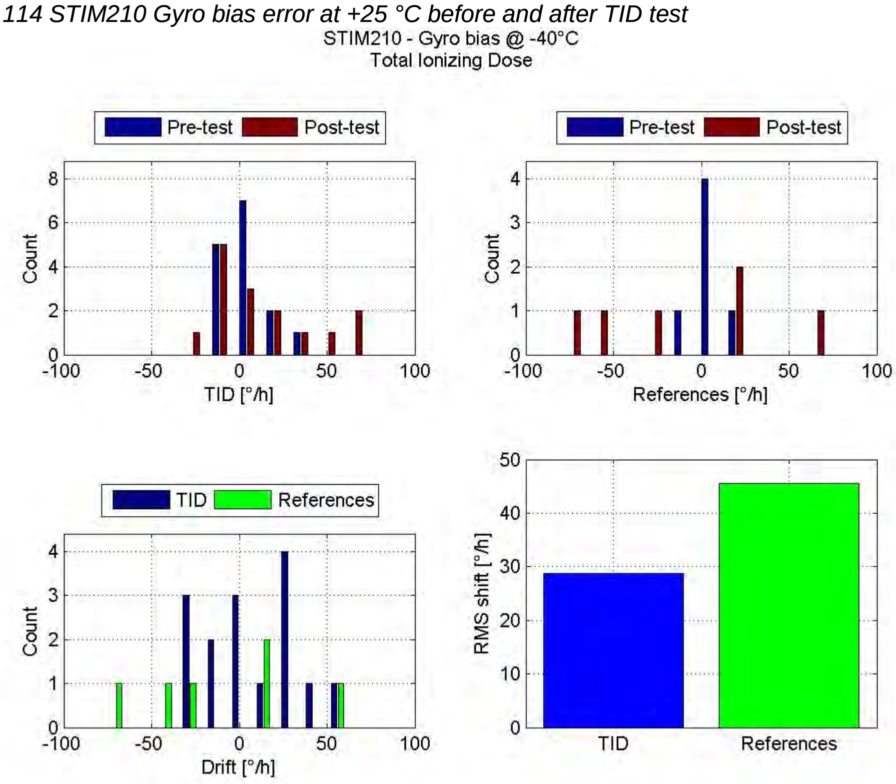


Figure 115 STIM210 Gyro bias error at -40 °C before and after TID test

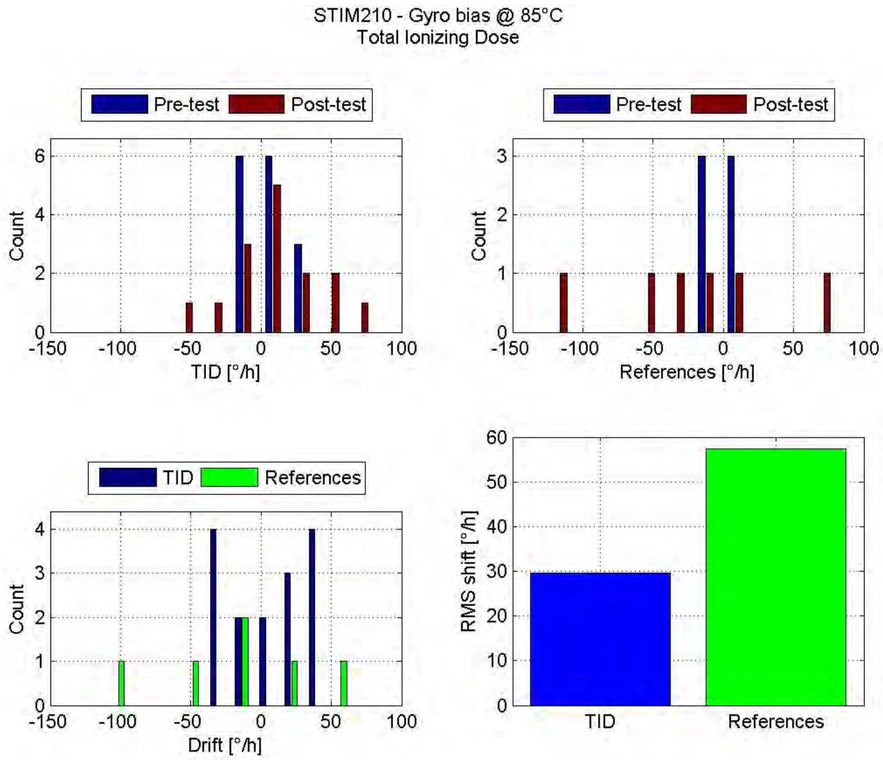


Figure 116 STIM210 Gyro bias error at 85 °C before and after TID test

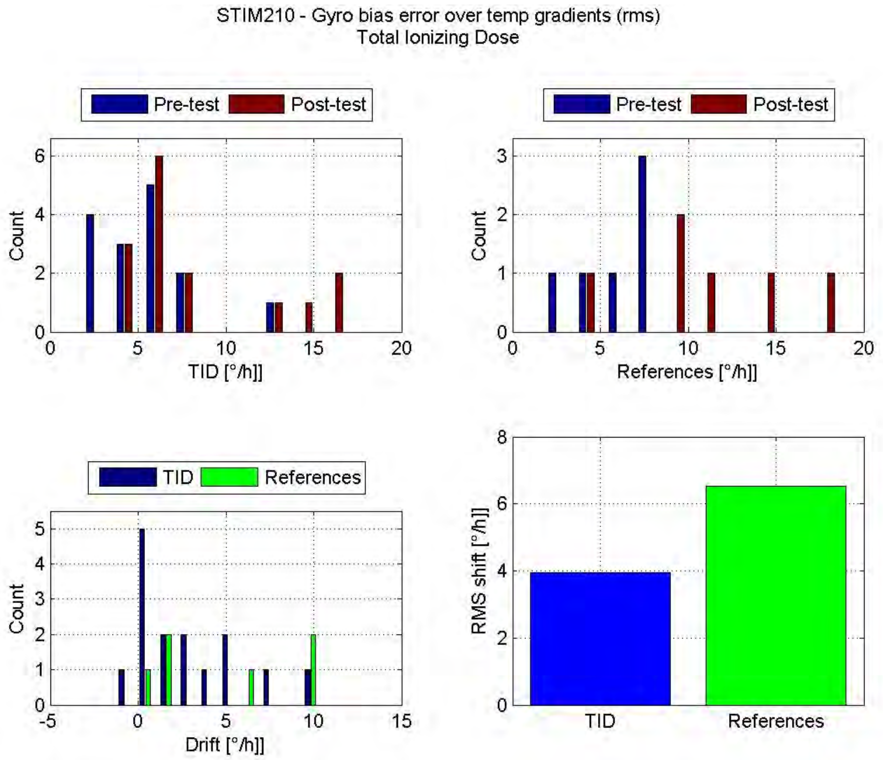


Figure 117 STIM210 Gyro RMS bias error over temperature gradients before and after TID test

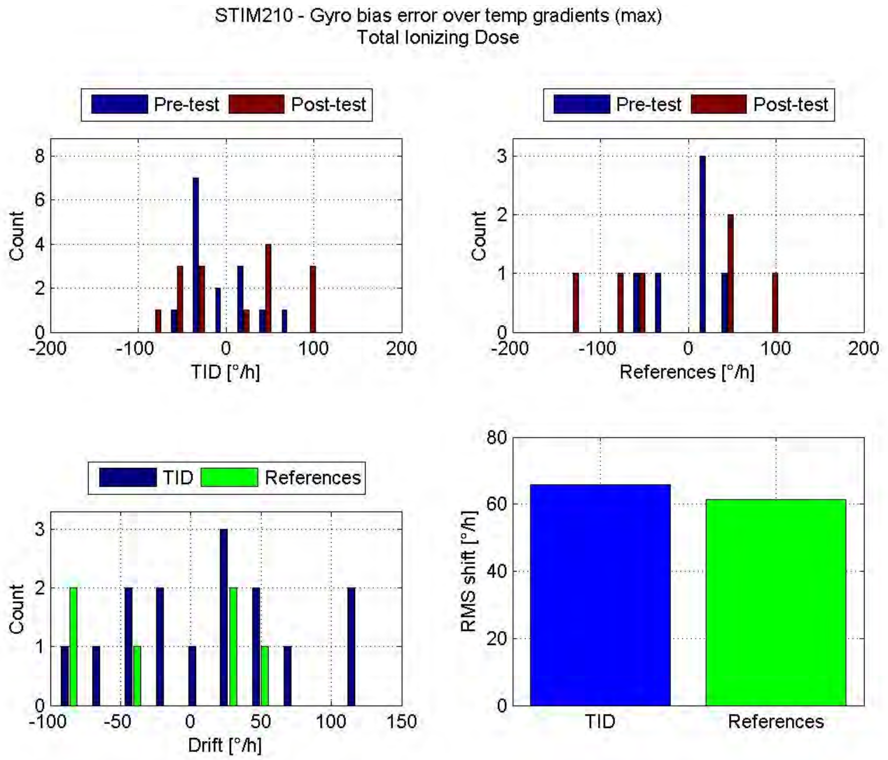


Figure 118 STIM210 Gyro maximum bias error over temperature gradients before and after TID test

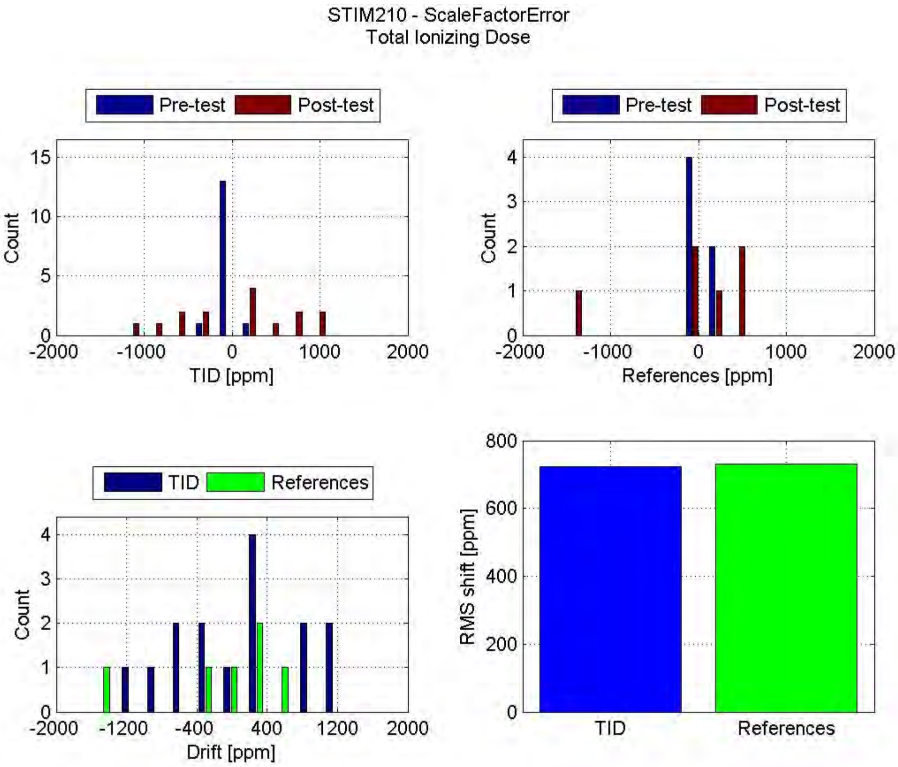


Figure 119 STIM210 Gyro scale factor error over temperature before and after TID test

D Production Test results comparisons before and after SEE radiation test

The following figures shows the performance before and after SEE radiation test on the key parameters bias shift and scale factor error

- **STIM300**

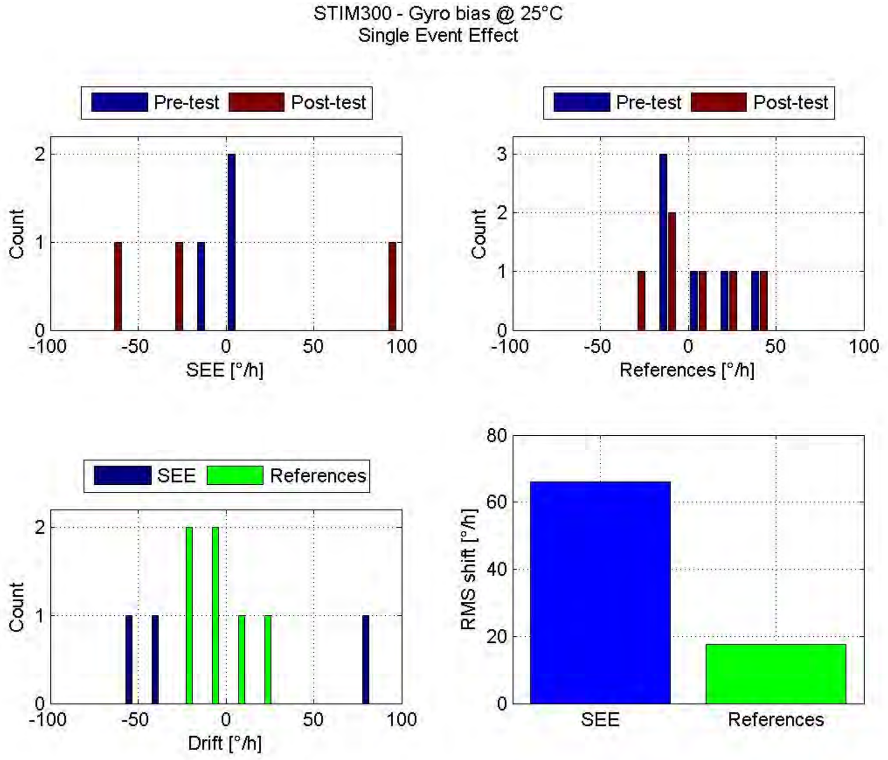


Figure 120 STIM300 Gyro bias error at +25 °C before and after SEE test

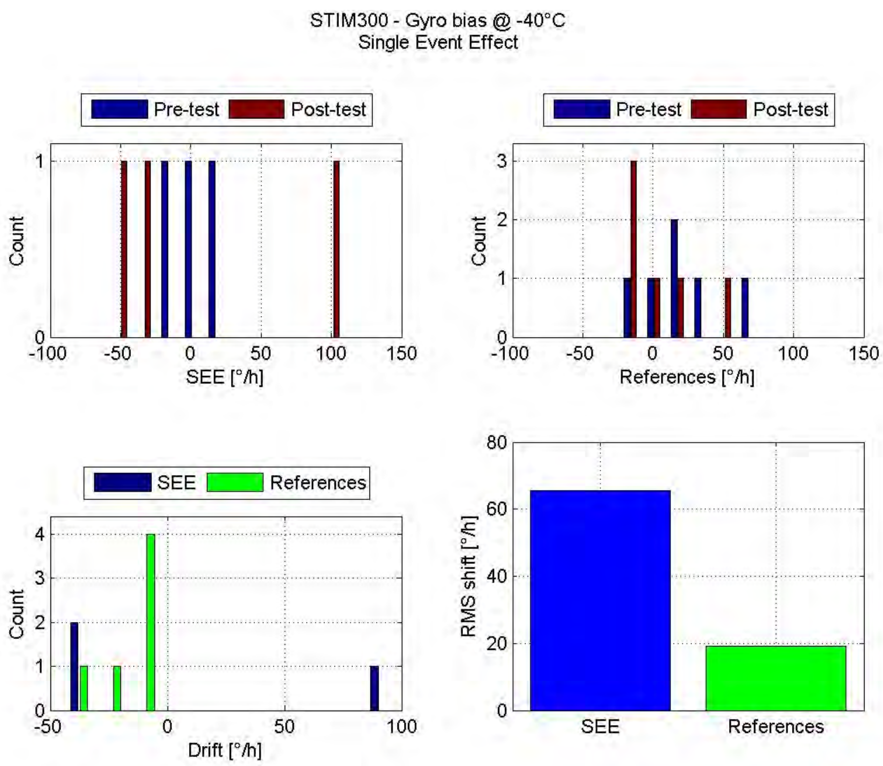


Figure 121 STIM300 Gyro bias error at -40 °C before and after SEE test

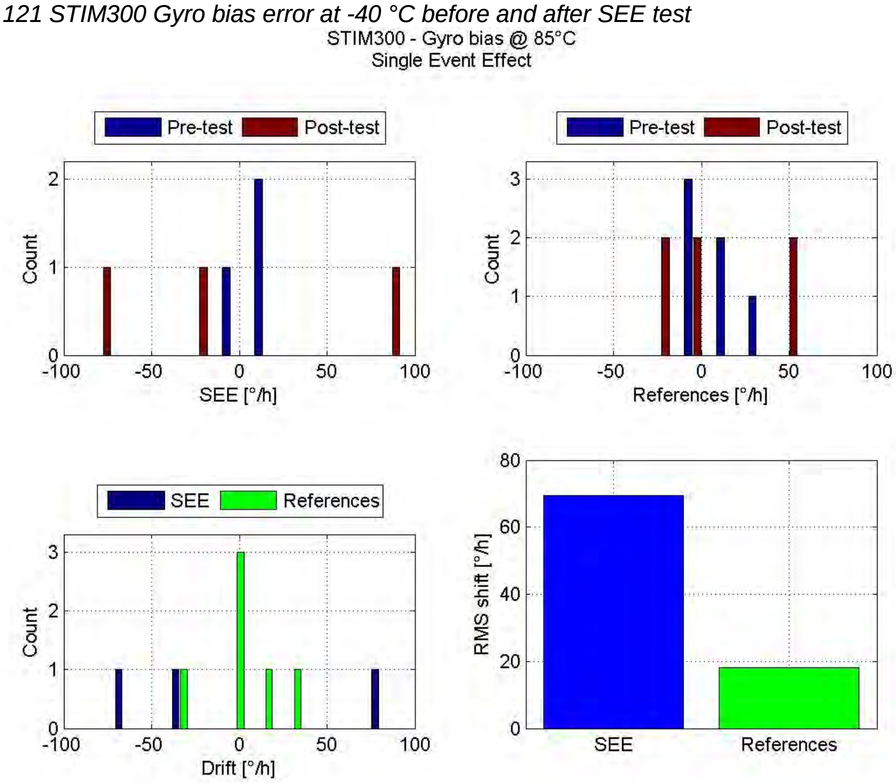


Figure 122 STIM300 Gyro bias error at 85 °C before and after SEE test

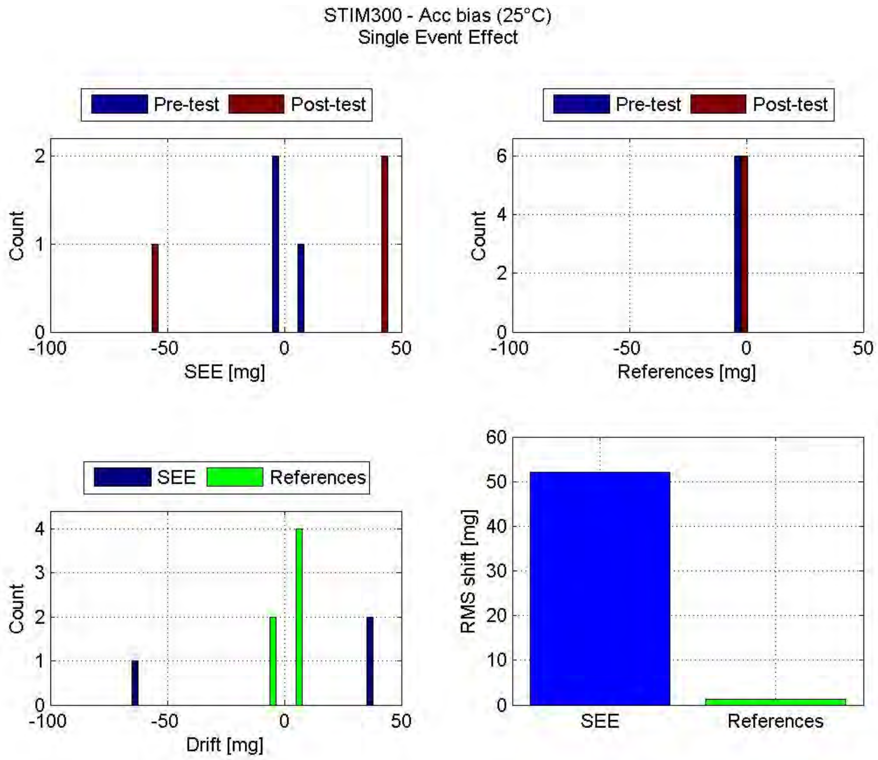


Figure 123 STIM300 Accelerometer bias error at +25 °C before and after SEE test

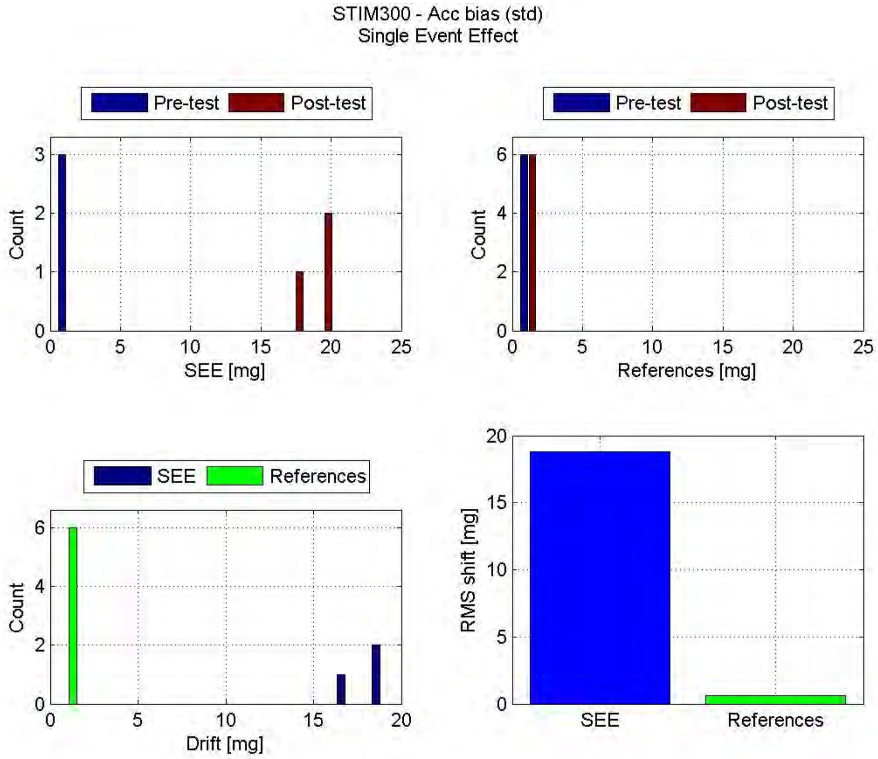


Figure 124 STIM300 Accelerometer RMS bias error over temperature at before and after SEE test

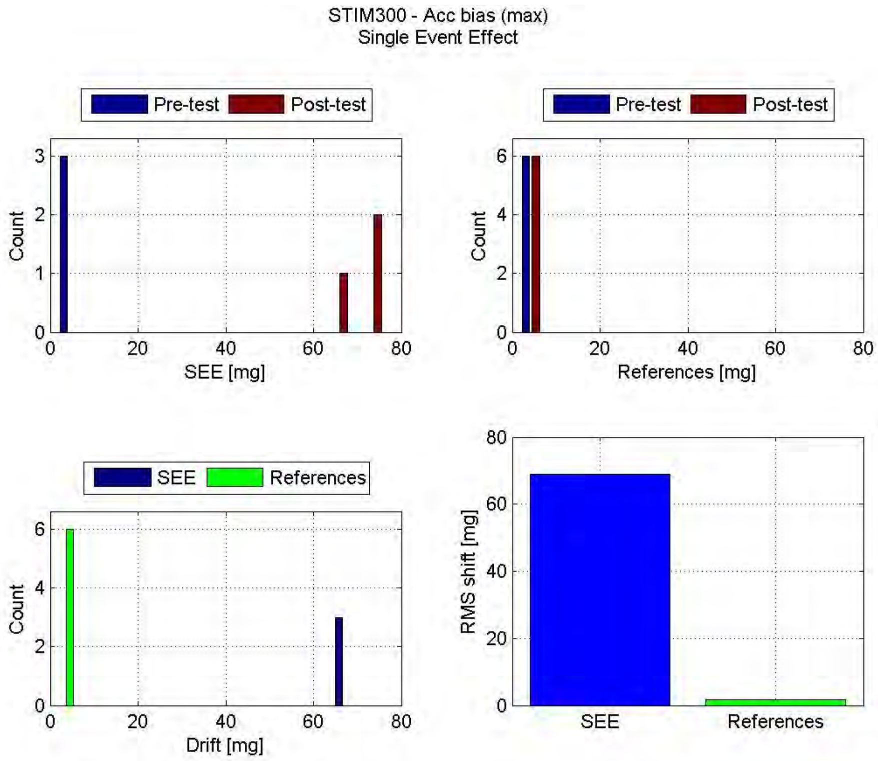


Figure 125 STIM300 Accelerometer maximum bias error over temperature before and after SEE test

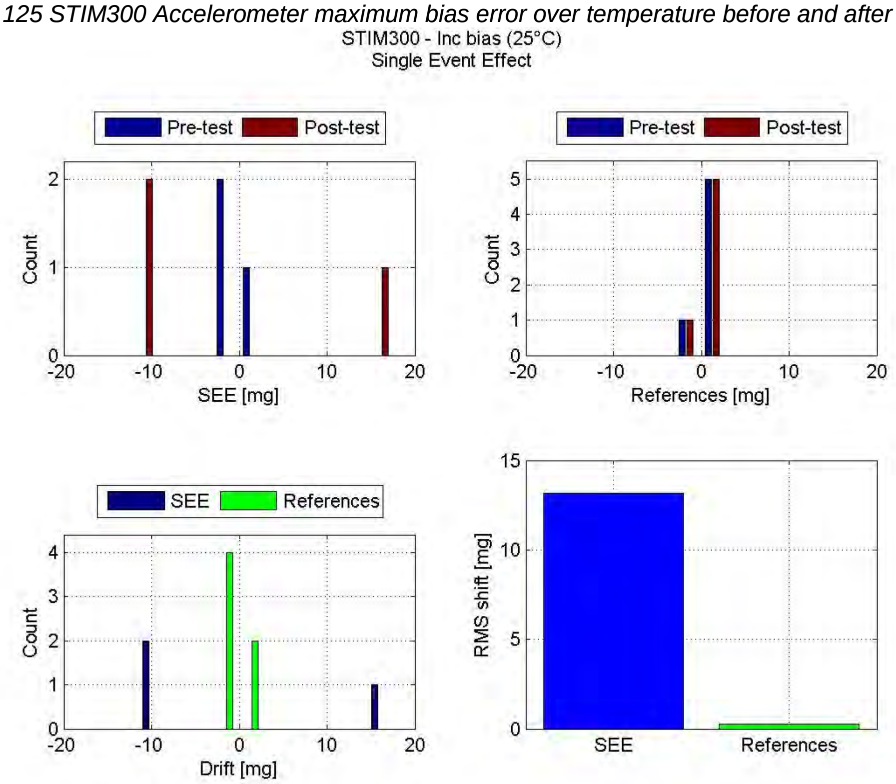


Figure 126 STIM300 Inclinometer bias error at +25 °C before and after SEE test

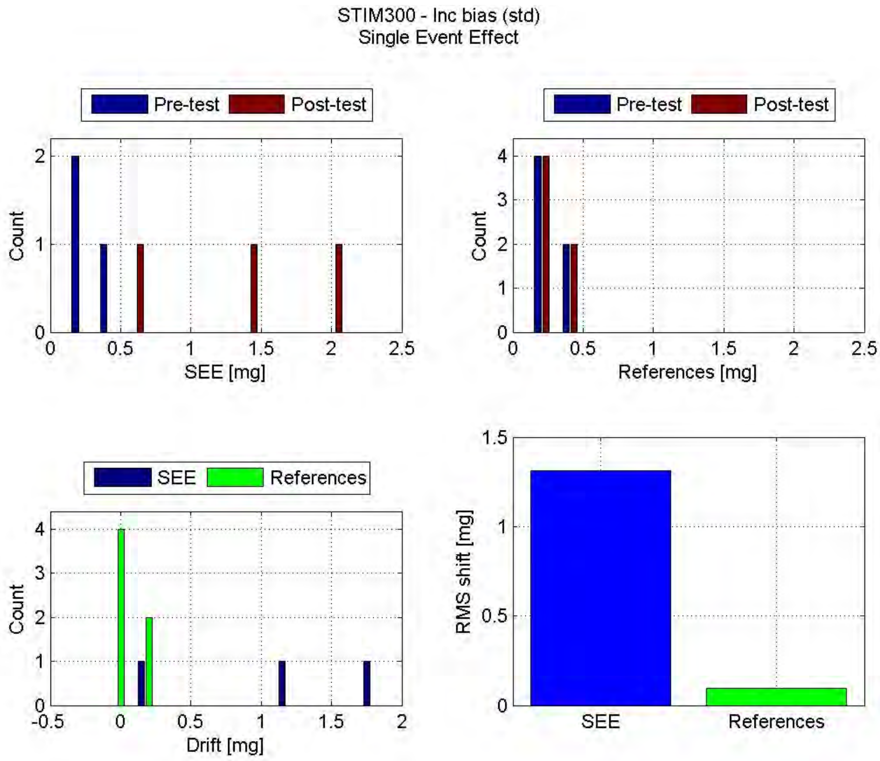


Figure 127 STIM300 Inclinometer RMS bias error over temperature before and after SEE test

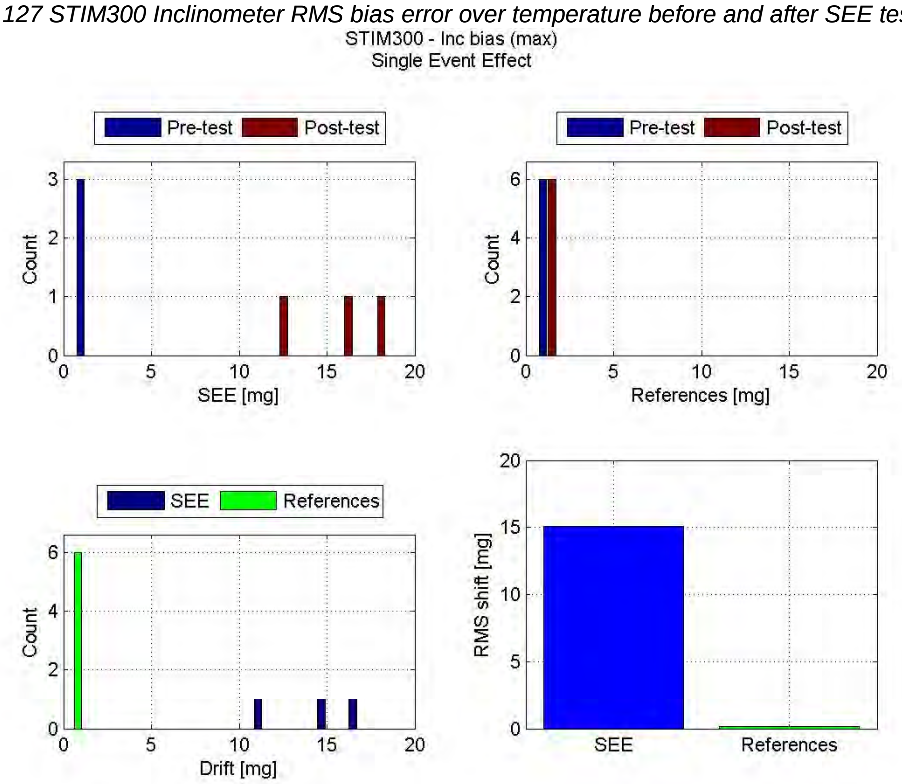


Figure 128 STIM300 Inclinometer maximum bias error over temperature before and after SEE test

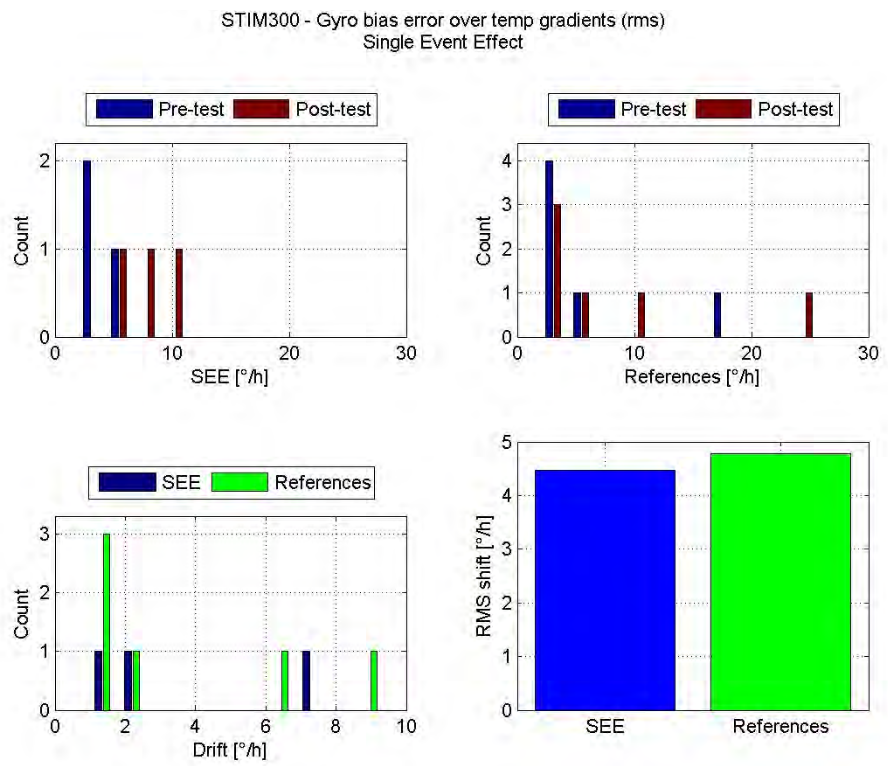


Figure 129 STIM300 Gyro RMS bias error over temperature gradients before and after SEE test

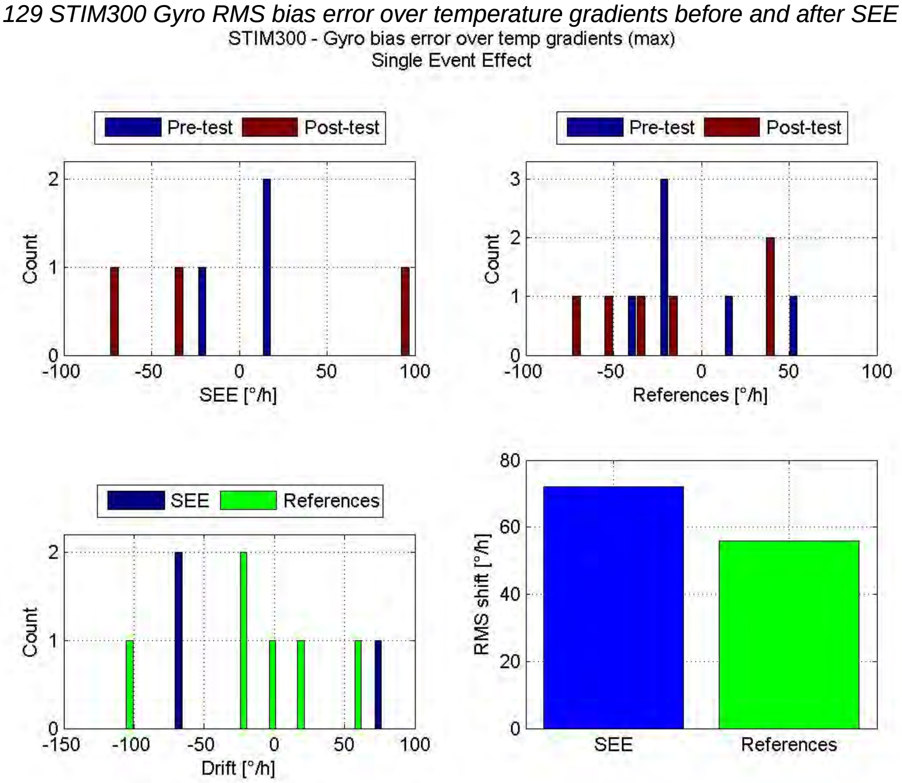


Figure 130 STIM300 Gyro maximum bias error over temperature gradients before and after SEE test

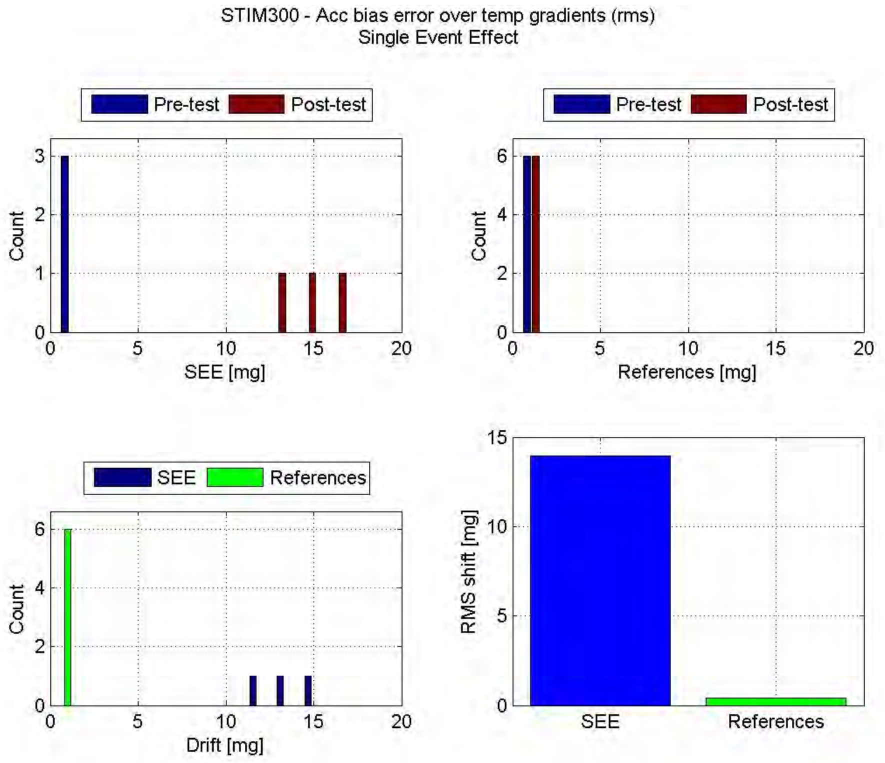


Figure 131 STIM300 Accelerometer RMS bias error over temperature gradients before and after SEE test

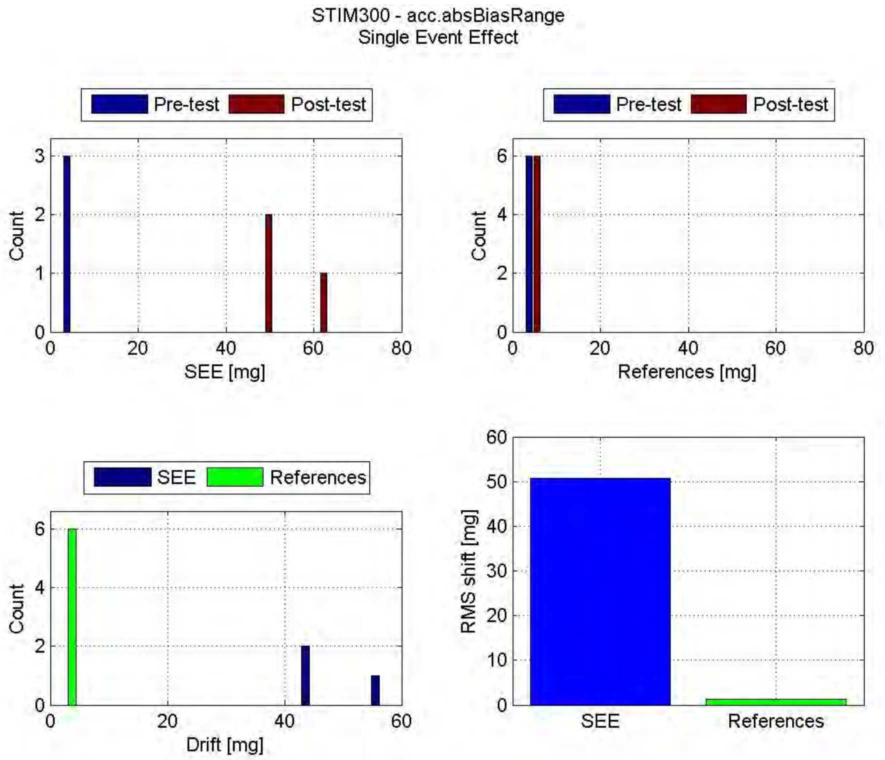


Figure 132 STIM300 Accelerometer maximum bias error over temperature gradients before and after SEE test

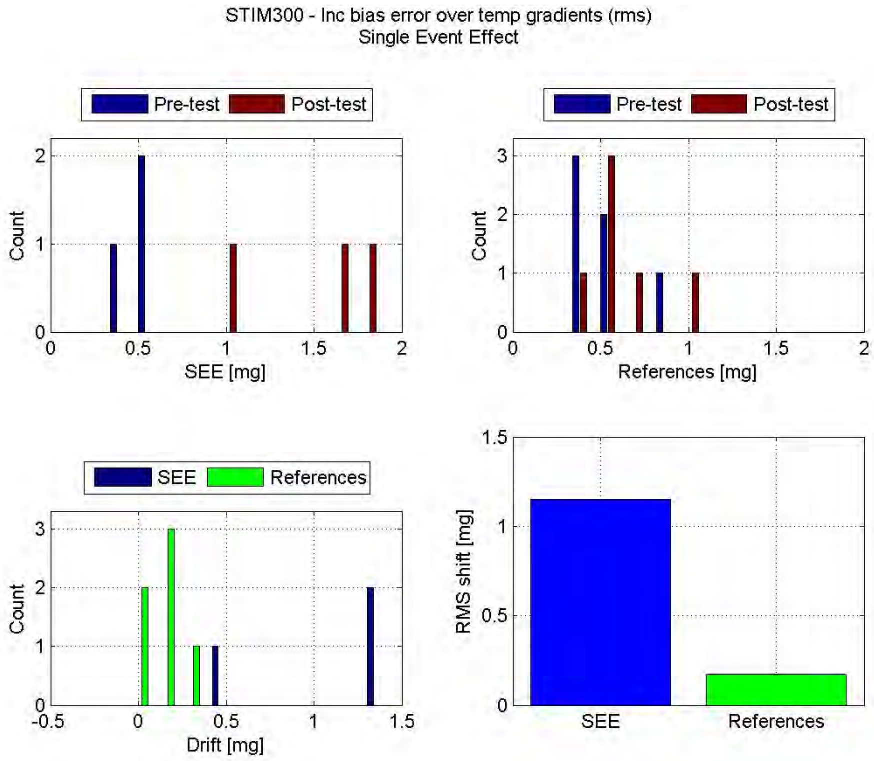


Figure 133 STIM300 Inclinometer RMS bias error over temperature gradients before and after SEE test

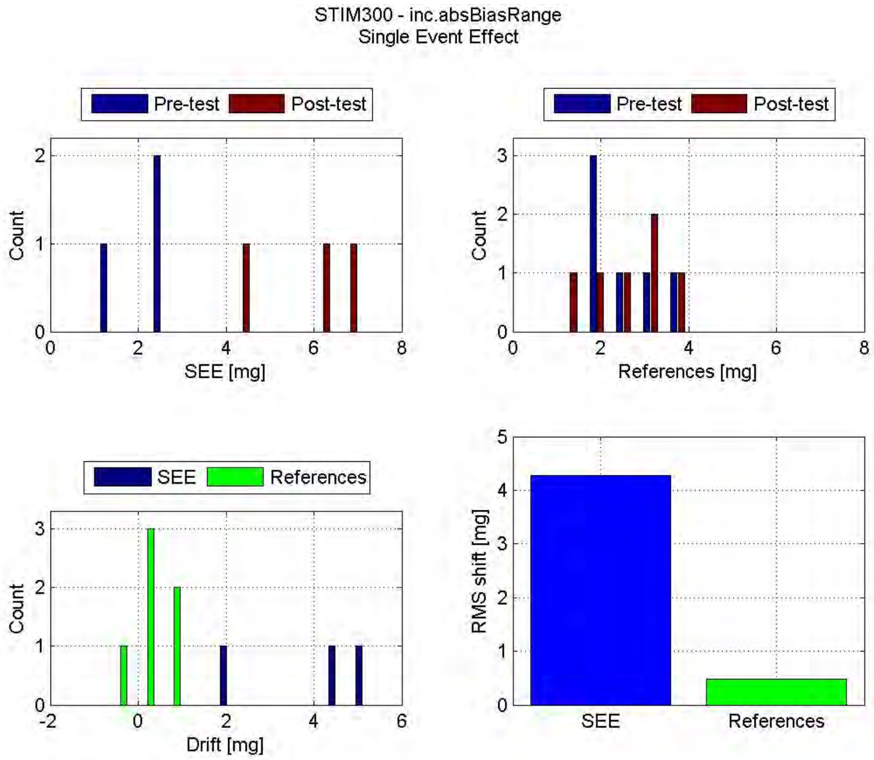


Figure 134 STIM300 Inclinometer maximum bias error over temperature gradients before and after SEE test

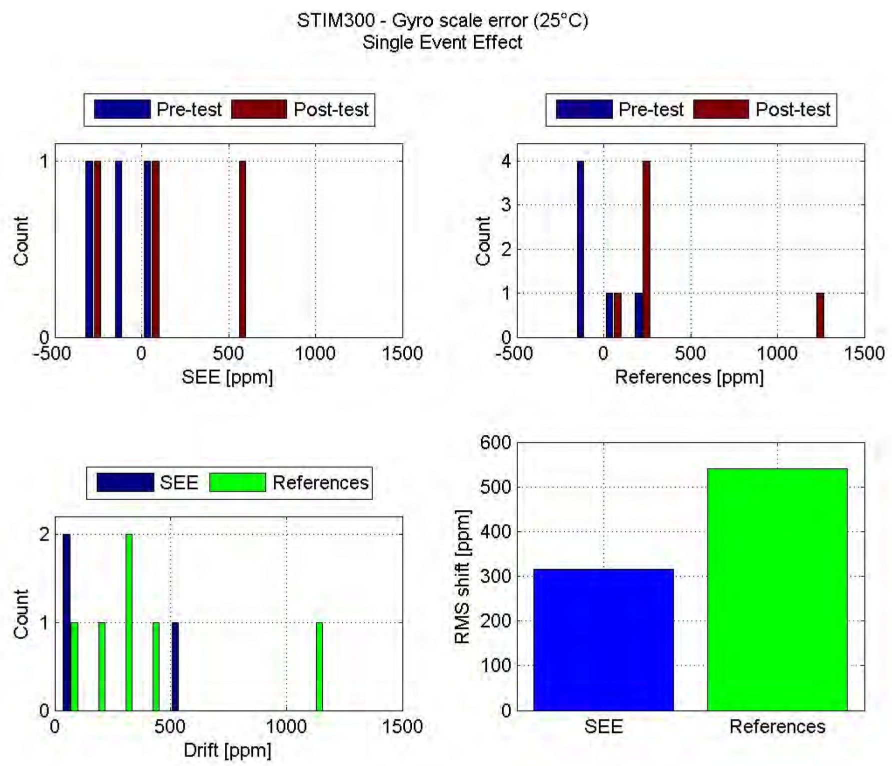


Figure 135 STIM300 Gyro scale factor error at +25 °C before and after SEE test

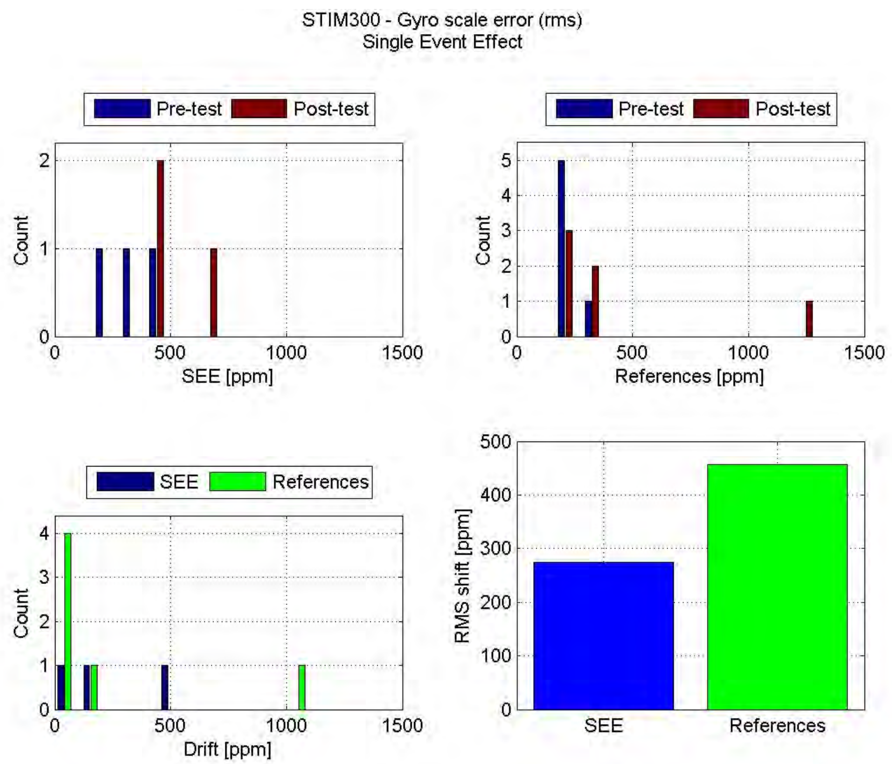


Figure 136 STIM300 Gyro RMS scale factor error over temperature before and after SEE test

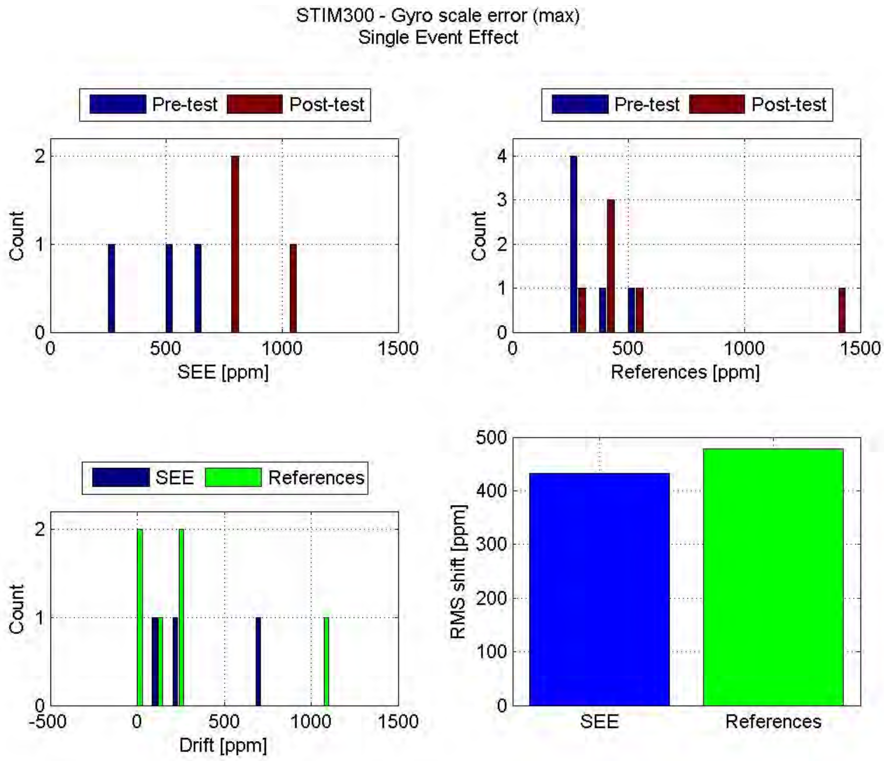


Figure 137 STIM300 Gyro maximum scale factor error over temperature before and after SEE test

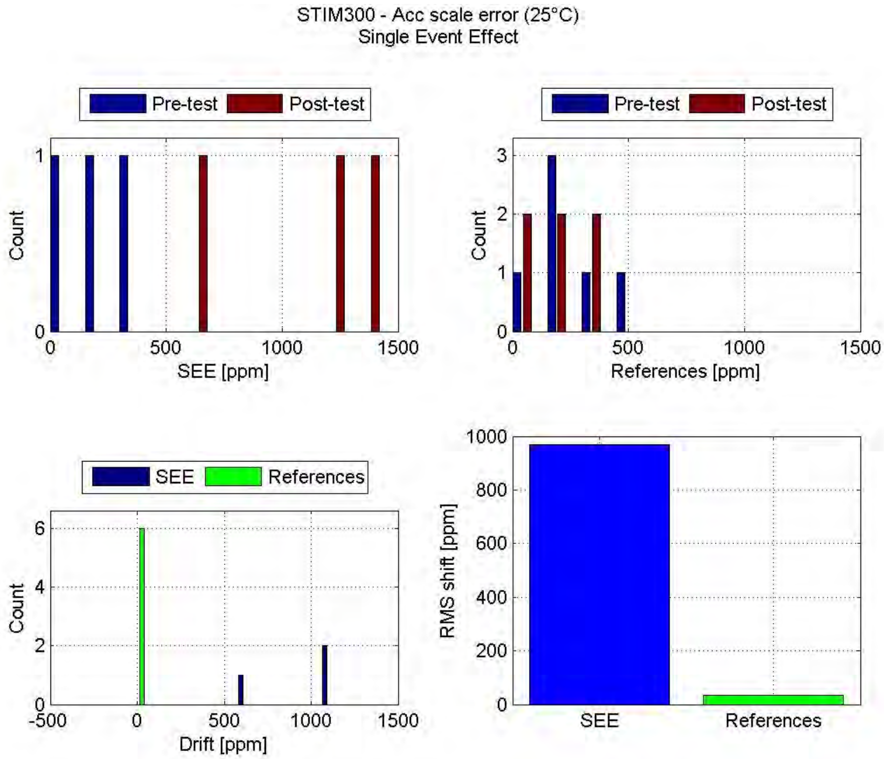


Figure 138 STIM300 Accelerometer scale factor error at +25 °C before and after SEE test

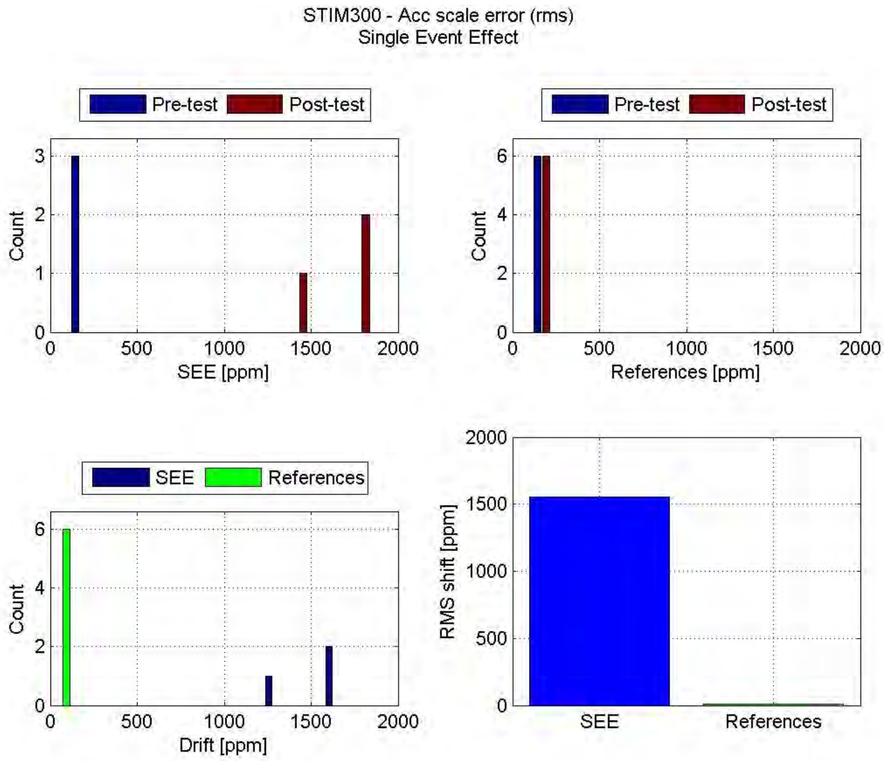


Figure 139 STIM300 Accelerometer RMS scale factor error over temperature before and after SEE test

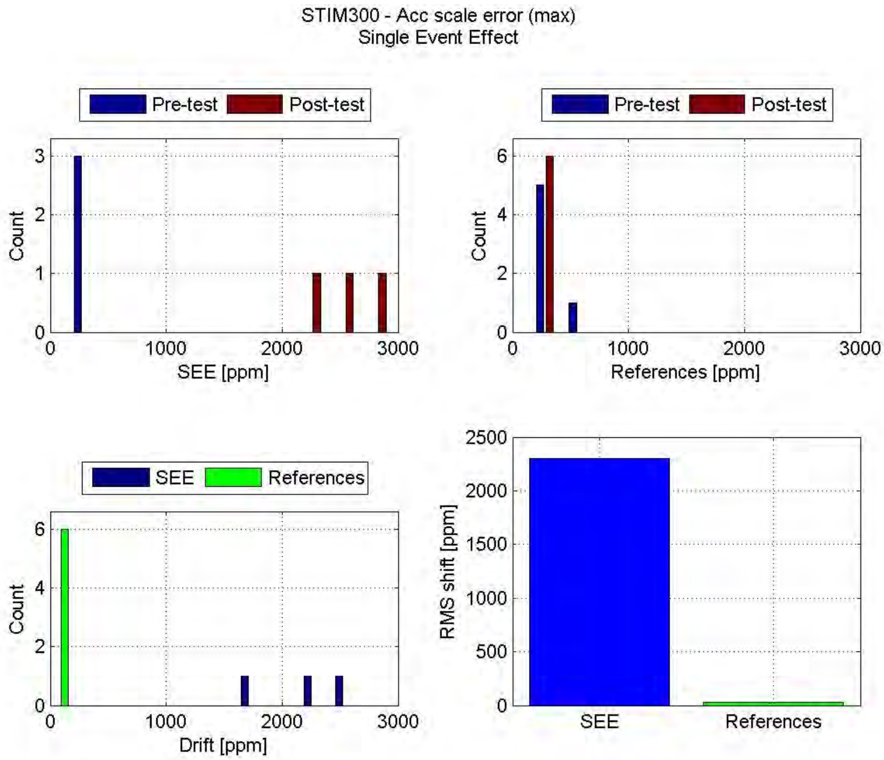


Figure 140 STIM300 Accelerometer maximum scale factor error over temperature before and after SEE test

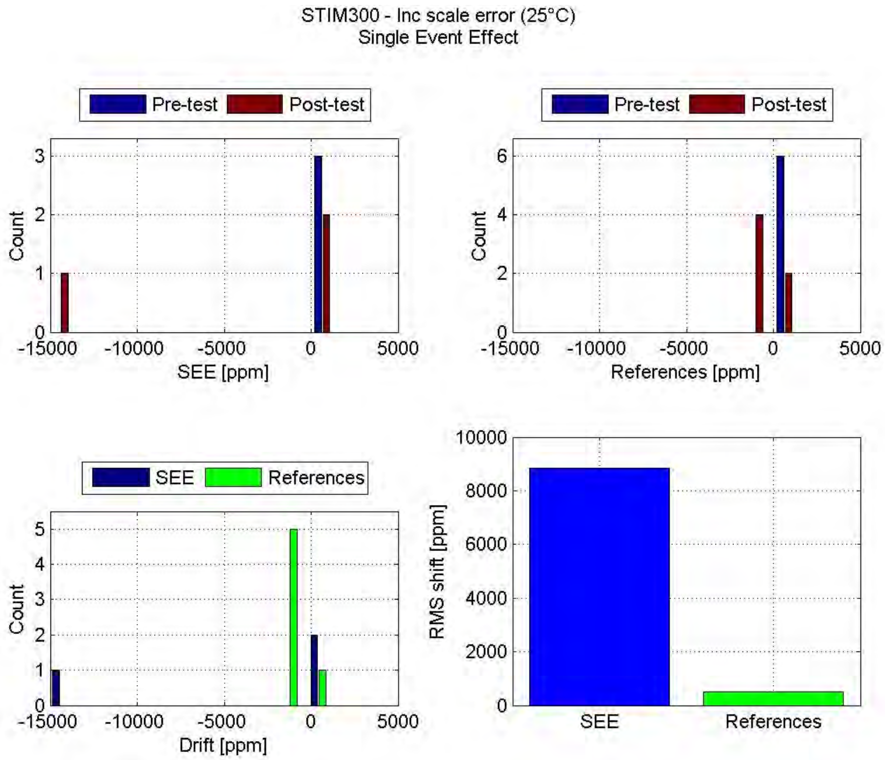


Figure 141 STIM300 Inclinometer scale factor error at +25 °C before and after SEE test

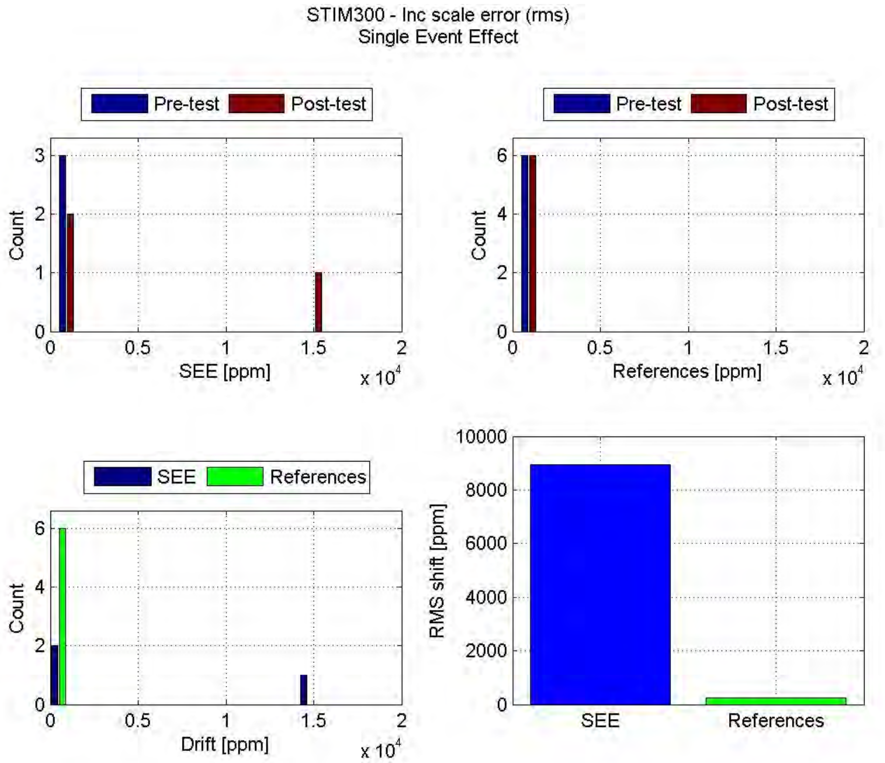


Figure 142 STIM300 Inclinometer RMS scale factor error over temperature before and after SEE test

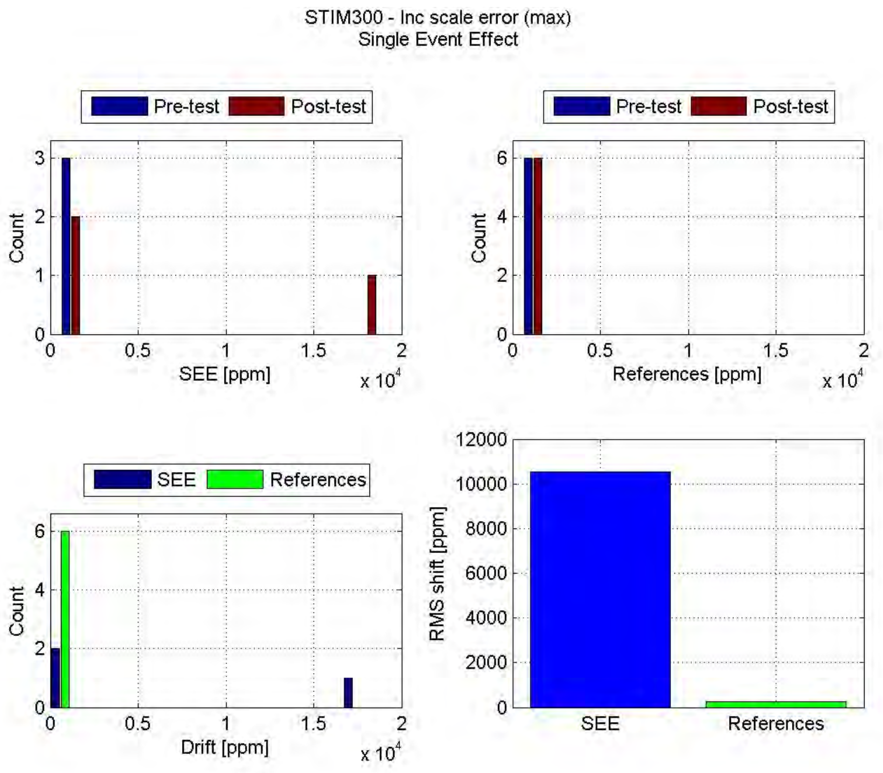


Figure 143 STIM300 Inclinometer maximum scale factor error over temperature before and after SEE test

- **STIM210**

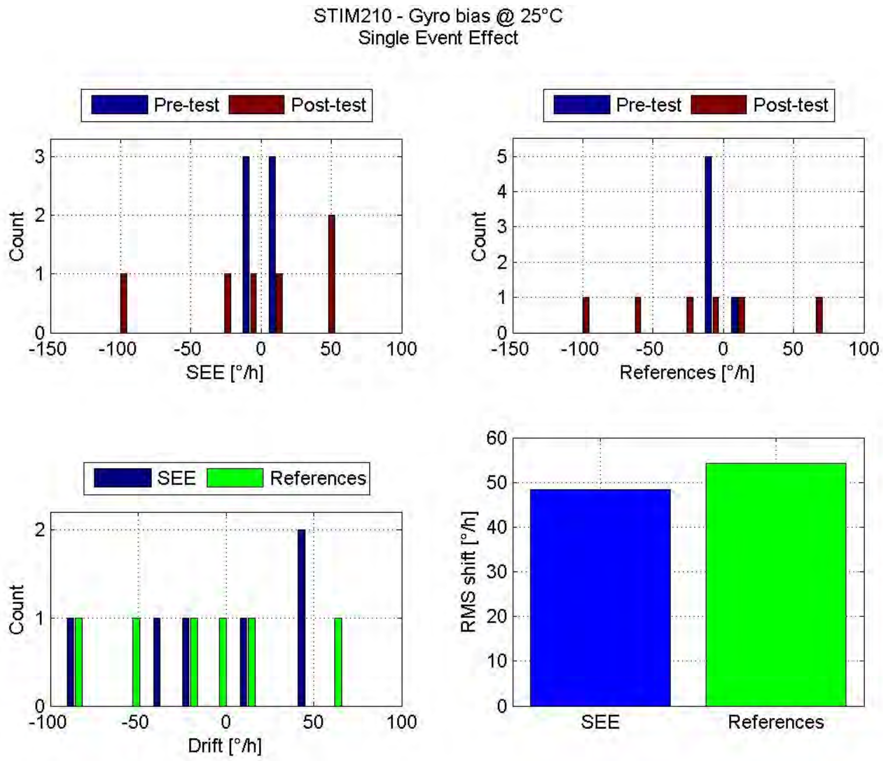


Figure 144 STIM210 Gyro bias error at +25 °C before and after SEE test

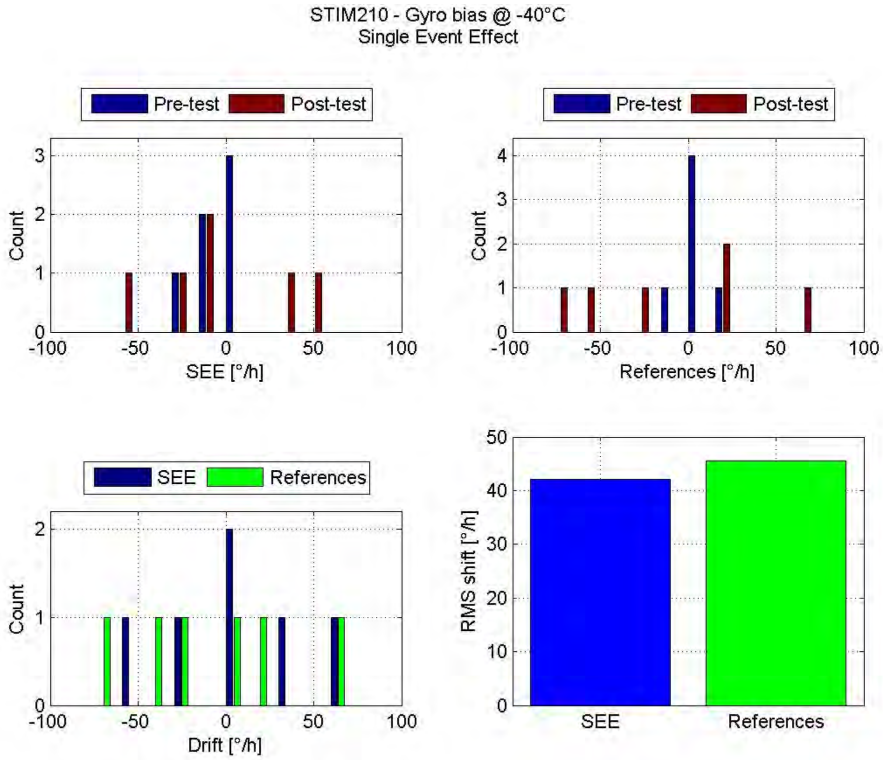


Figure 145 STIM210 Gyro bias error at -40 °C before and after SEE test

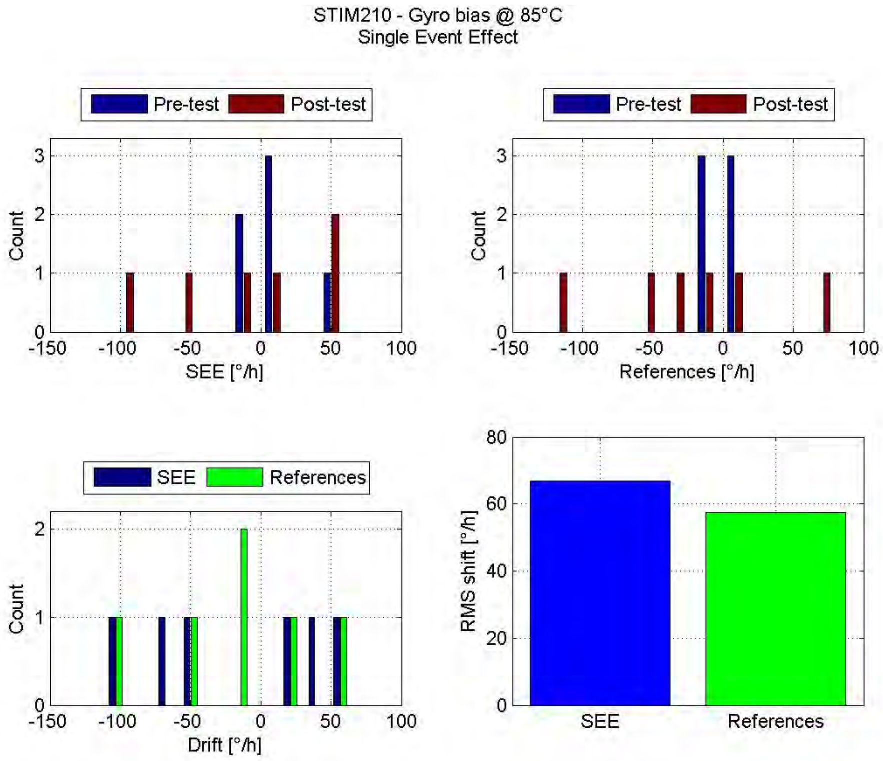


Figure 146 STIM210 Gyro bias error at 85 °C before and after SEE test

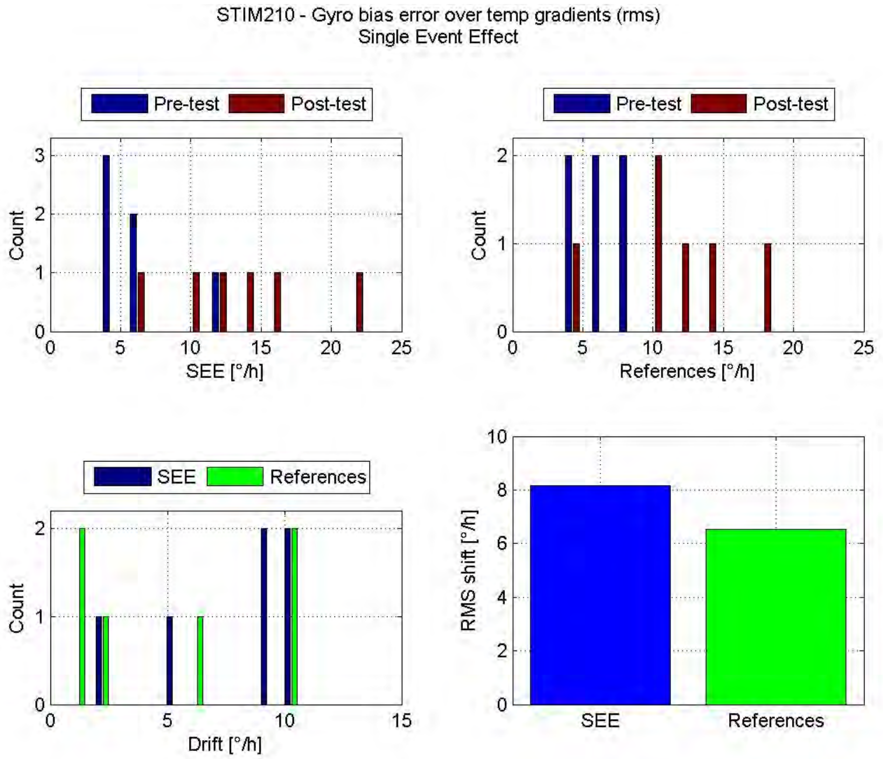


Figure 147 STIM210 Gyro RMS bias error over temperature gradients before and after SEE test

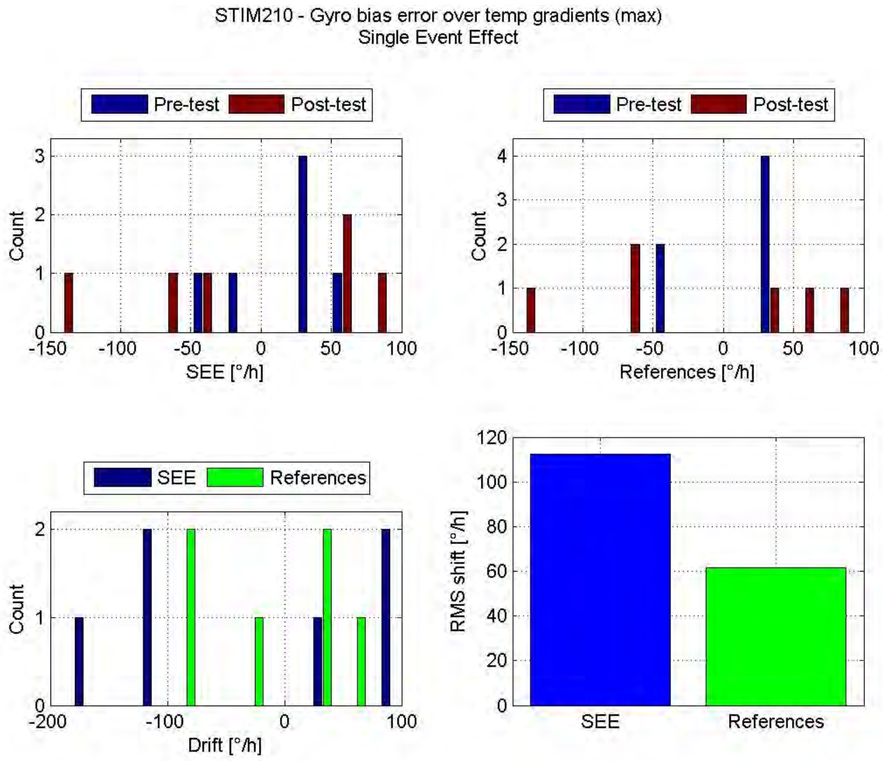


Figure 148 STIM210 Gyro maximum bias error over temperature gradients before and after SEE test

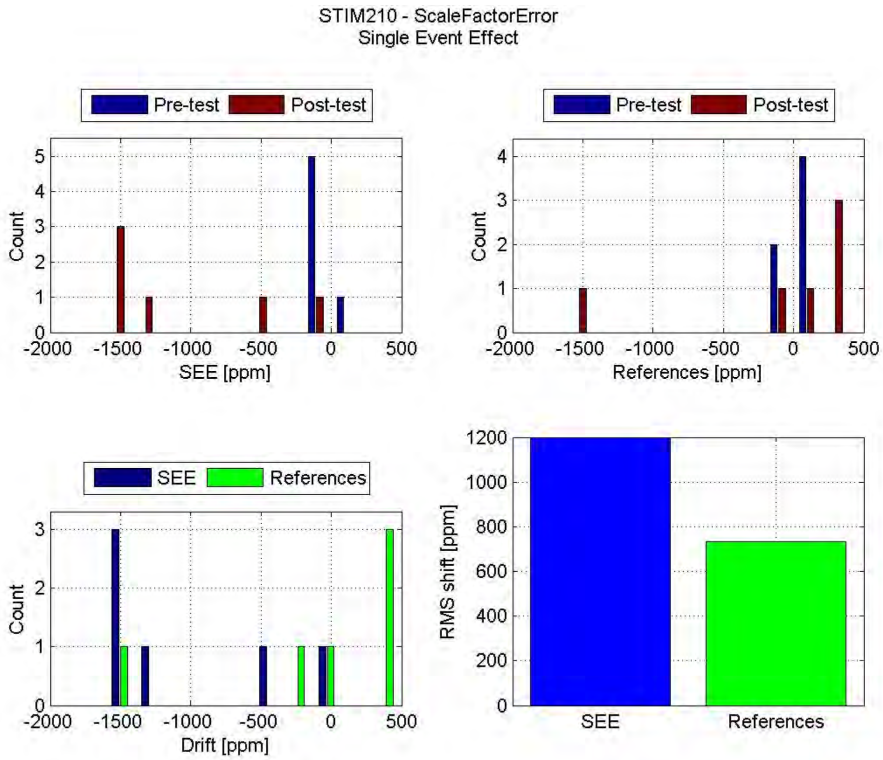


Figure 149 STIM210 Gyro scale factor error over temperature before and after SEE test

E Replaced electronic components

During failure analysis of STIM210 and STIM300, UUTs that showed hardware failure after irradiation, the components listed in Table 20 has been found to be malfunctioning and replaced in order to clear the hardware failure indication.

Table 20 Replaced electronic components

Component	Manufacturers part number	Manufacturer
Reset	TPS3808G01DBVTG4	Texas Instruments
Vreg1V8	LT1763CDE-1.8#PBF	Linear Technology
Vreg3V3	TPS62290DRVTG4	Texas Instruments
VReg5V	LT1763CDE-5#PBF	Linear Technology
VRef2V048	ADR440ARMZ	Analog Devices
VRef2V5	ADR441ARMZ	Analog Devices
VRef5V	ADR445ARMZ	Analog Devices
DAC	AD5308ARUZ	Analog Devices
ACC (X, Y and Z)	MS9010	Colibrys

F SEE: Log file

Table 21: SEE-Log file (Part 1): General settings and times of individual runs

Run #	Product	UUT	Proton energy [MeV]	Data start	Data stop	Beam start	Beam Stop	Run length
6	STIM300	1	120	23.10.2018 23:46:36	24.10.2018 00:00:29	23.10.2018 23:47:04	23.10.2018 23:59:43	759
7	STIM300	2	120	24.10.2018 00:48:23	24.10.2018 00:50:30	24.10.2018 00:48:42	24.10.2018 00:50:26	104
8	STIM300	2	120	24.10.2018 01:01:17	24.10.2018 01:03:35	24.10.2018 01:02:12	24.10.2018 01:03:16	64
9	STIM300	2	60	24.10.2018 01:26:29	24.10.2018 01:47:24	24.10.2018 01:26:51	24.10.2018 01:49:48	1377
10	STIM300	3	30	24.10.2018 02:48:20	24.10.2018 03:07:15	24.10.2018 02:48:40	24.10.2018 03:13:37	1497
11	STIM300	3	30	24.10.2018 03:44:11	24.10.2018 03:58:33	24.10.2018 03:44:49	24.10.2018 03:58:25	816
12	STIM300	4	200	24.10.2018 20:43:07	24.10.2018 20:48:35	24.10.2018 20:43:45	24.10.2018 20:48:32	287
13	STIM300	4	200	24.10.2018 20:56:43	24.10.2018 21:07:50	24.10.2018 20:56:52	24.10.2018 21:07:43	651
14	STIM300	3	200	24.10.2018 21:18:51	24.10.2018 21:35:11	24.10.2018 21:19:02	24.10.2018 21:34:06	904
15	STIM300	5	20	24.10.2018 21:44:43	24.10.2018 22:37:19	24.10.2018 21:45:13	24.10.2018 22:37:15	3122
16	STIM300	5	20	24.10.2018 22:38:36	24.10.2018 22:41:27	24.10.2018 22:39:23	24.10.2018 22:41:57	154
17	STIM210	1	200	24.10.2018 23:35:30	24.10.2018 23:41:18	24.10.2018 23:35:31	24.10.2018 23:41:17	346
18	STIM210	1	200	24.10.2018 23:47:45	25.10.2018 00:09:02	24.10.2018 23:47:59	25.10.2018 00:08:58	1259
19	STIM210	2	120	25.10.2018 00:21:00	25.10.2018 00:30:54	25.10.2018 00:21:11	25.10.2018 00:30:39	568
20	STIM210	2	120	25.10.2018 00:36:41	25.10.2018 00:53:16	25.10.2018 00:37:02	25.10.2018 00:52:45	943
21	STIM210	3	60	25.10.2018 01:09:55	25.10.2018 01:19:31	25.10.2018 01:10:12	25.10.2018 01:19:30	558
22	STIM210	3	60	25.10.2018 01:27:19	25.10.2018 01:40:37	25.10.2018 01:28:06	25.10.2018 01:40:05	719
23	STIM210	4	30	25.10.2018 02:08:36	25.10.2018 02:46:59	25.10.2018 02:08:54	25.10.2018 02:46:34	2260
24	STIM210	5	20	25.10.2018 02:51:57	25.10.2018 03:05:06	25.10.2018 02:52:32	25.10.2018 03:05:05	753
25	STIM210	5	20	25.10.2018 03:16:11	25.10.2018 03:33:49	25.10.2018 03:16:29	25.10.2018 03:34:00	1051
26	STIM210	5	20	--	--	--	--	--
27	STIM210	5	20	None	None	25.10.2018 03:43:57	25.10.2018 03:47:38	221

Table 22: SEE-Log file (Part 2): (identical to Table 7 *in Section 7.2.1)*

Run #	Product	UUT	Proton energy [MeV]	Total fluence [cm-2]	Flux [cm-2 s-1]	power cycles	Comment
6	STIM300	1	120	1.00E+11	1.32E+08	2	
7	STIM300	2	120	1.32E+10	1.30E+08	2	Interrupted due to early errors
8	STIM300	2	120	8.05E+09	1.28E+08	0	Interrupted due to early errors
9	STIM300	2	60	9.49E+10	7.73E+07	20	Due to a power shutdown at the test laptop, premature end of power supply data
10	STIM300	3	30	6.47E+10	4.32E+07	1	Premature end of power supply data due to a power shutdown at the test laptop

11	STIM300	3	30	3.53E+10	4.32E+07	0	Continuation of run #10
12	STIM300	4	200	1.77E+10	6.23E+07	12	High number of current increases → prepare new run at reduced flux
13	STIM300	4	200	1.13E+10	1.74E+07	22	Continuation of run #12 at reduced flux. Current increases getting more frequent with time. Interruption to run diagnostics. Errors in diagnostics → no further tests with UUT
14	STIM300	3	200	1.55E+10	1.71E+07	18	Interruption to run diagnostics on UUT, Reference voltage failing → no further tests with UUT
15	STIM300	5	20	9.57E+10	3.26E+07	2	Beam offline for approx. 2 min
16	STIM300	5	20	4.99E+09	3.22E+07	0	Premature end of power supply data due to a power shutdown at the test laptop
17	STIM210	1	200	6.22E+09	1.81E+07	11	Interruption to run diagnostics on UUT
18	STIM210	1	200	2.15E+10	1.72E+07	46	continuation of run #17
19	STIM210	2	120	3.70E+10	6.55E+07	19	Interruption to run diagnostics on UUT
20	STIM210	2	120	6.30E+10	6.75E+07	11	continuation of run #19
21	STIM210	3	60	4.36E+10	7.84E+07	8	Run ended due to a power shutdown at the test laptop. While at other instances this was abrupt, here the laptop froze before crashing, allowing to shut down the beam before loss of data.
22	STIM210	3	60	5.63E+10	7.86E+07	9	continuation of run #21
23	STIM210	4	30	1.00E+11	4.43E+07	1	
24	STIM210	5	20	2.52E+10	3.36E+07	0	Run ended due to a power shutdown at the test laptop. While at other instances this was abrupt, here the laptop froze before crashing, allowing to shut down the beam before loss of data.
25	STIM210	5	20	3.50E+10	3.34E+07	0	Continuation of run #24, Premature end of power supply data due to a power shutdown at the test laptop
26	STIM210	5	20	--	--	--	beam was started for <1 second but UUT was not ready yet.
27	STIM210	5	20	7.36E+09	3.36E+07	--	Continuation of runs #24 and 25, Premature end of power supply data due to a power shutdown at the test laptop

G SEE: Proton fluxes and current plots

For each run the proton flux, the UUT current and the UUT voltage are displayed.
Vertical green lines indicate the start and stop of the beam given by the beginning and end of the data acquisition in the PSI log files.
Red squares indicate a power cycle or power shutdown (including the final shutdown at the end of the run).
Abrupt jumps in the currents are in the majority of instances from one data point to the next.

Figure 150: Run #6: STIM300 UUT-Nr.1, E(proton) = 120 MeV

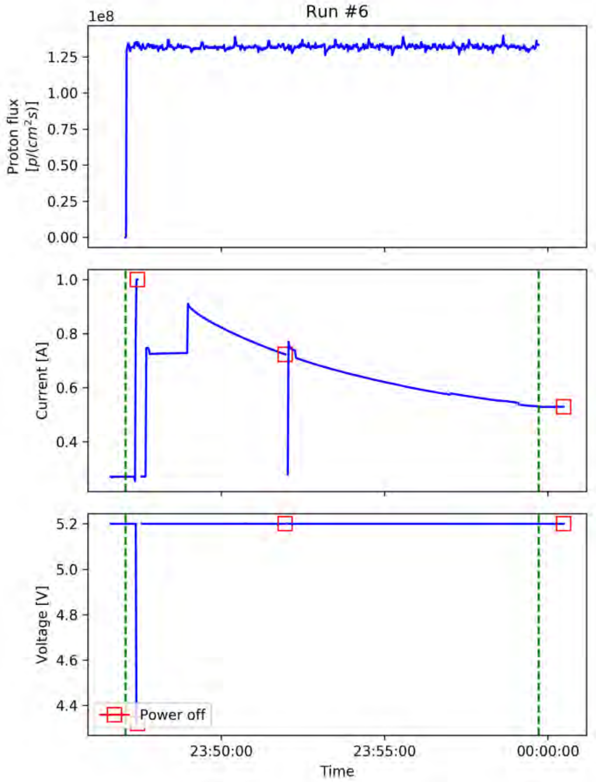


Figure 151: Run #7: STIM300 UUT-Nr.2, E(proton) = 120 MeV

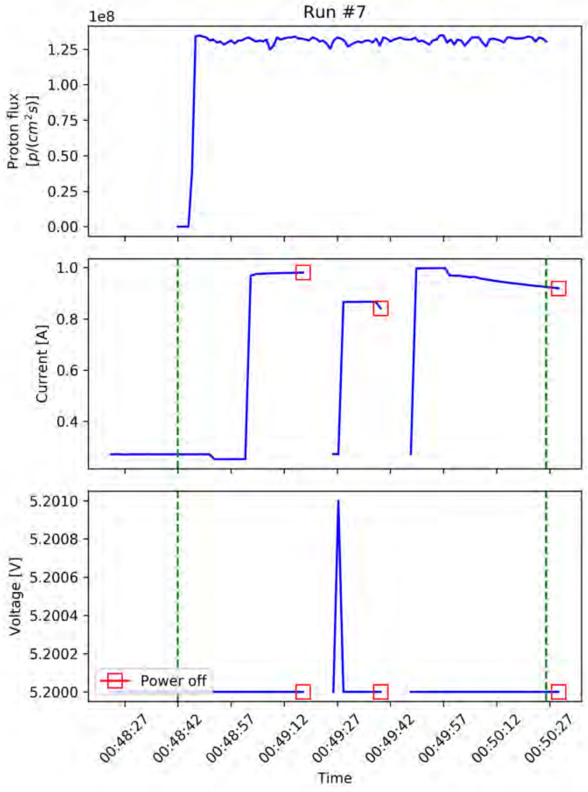


Figure 152: Run #8: STIM300 UUT-Nr.2, E(proton) = 120 MeV

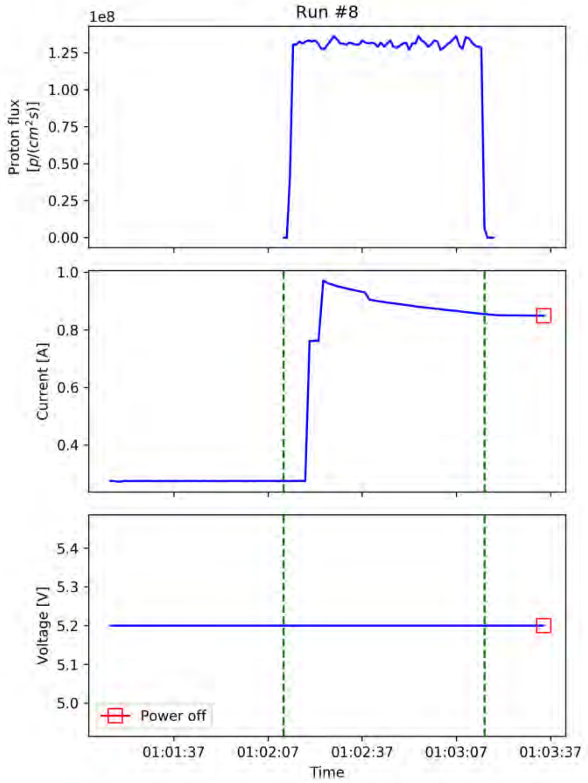
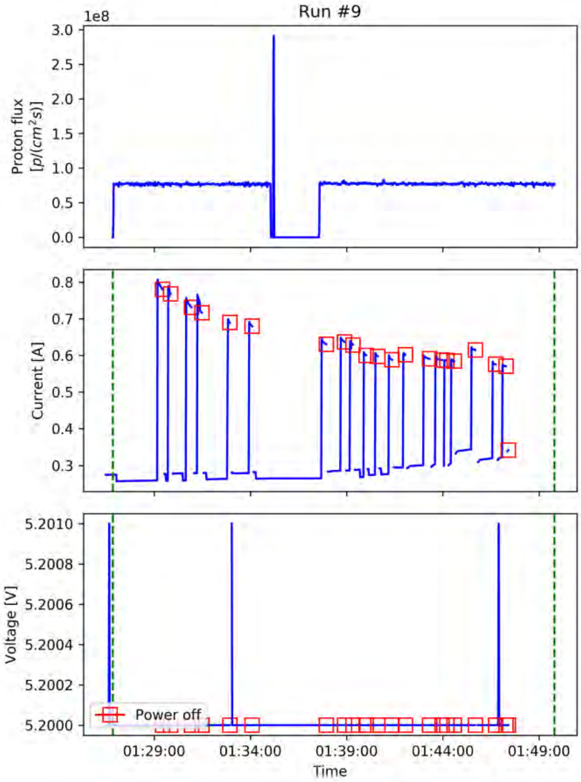
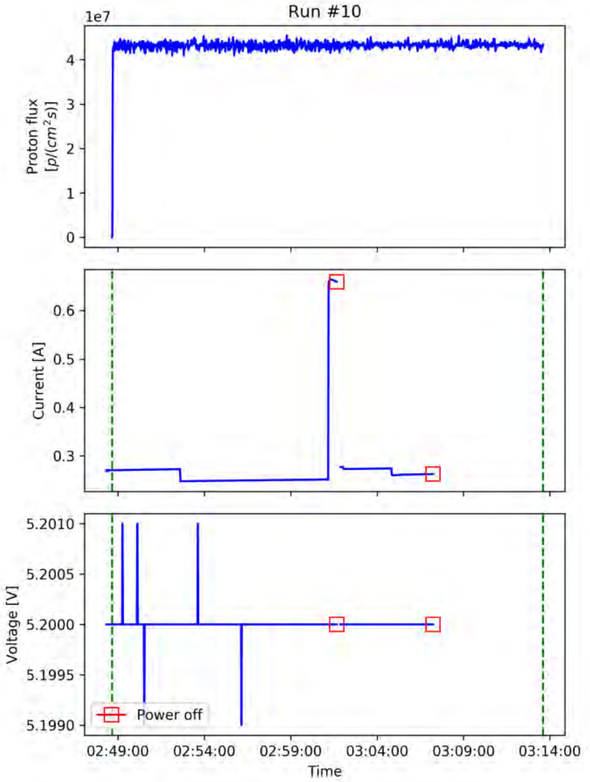


Figure 153: Run #9: STIM300 UUT-Nr.2, E(proton) = 60 MeV



Due to a power shutdown at the test laptop, premature end of power supply data

Figure 154: Run #10: STIM300 UUT-Nr.3, E(proton) = 30 MeV



Due to a power shutdown at the test laptop, premature end of power supply data

Figure 155: Run #11: STIM300 UUT-Nr.3, E(proton) = 30 MeV

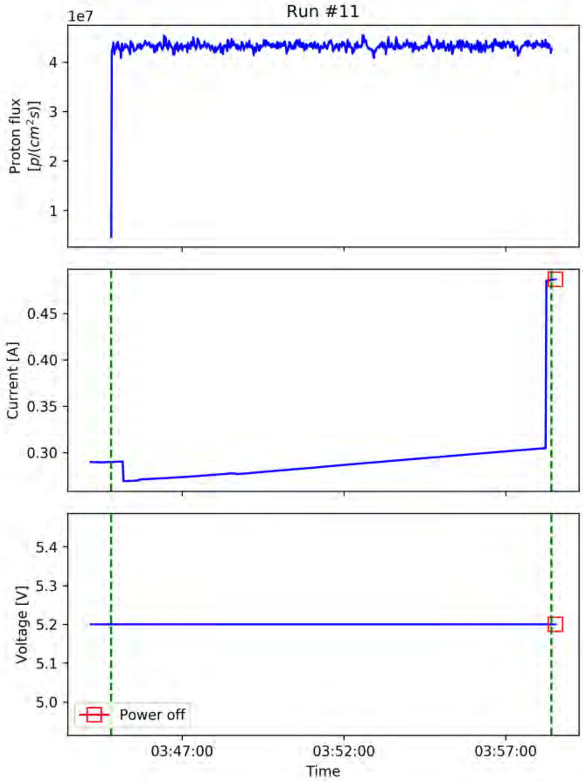


Figure 156: Run #12: STIM300 UUT-Nr.4, E(proton) = 200 MeV

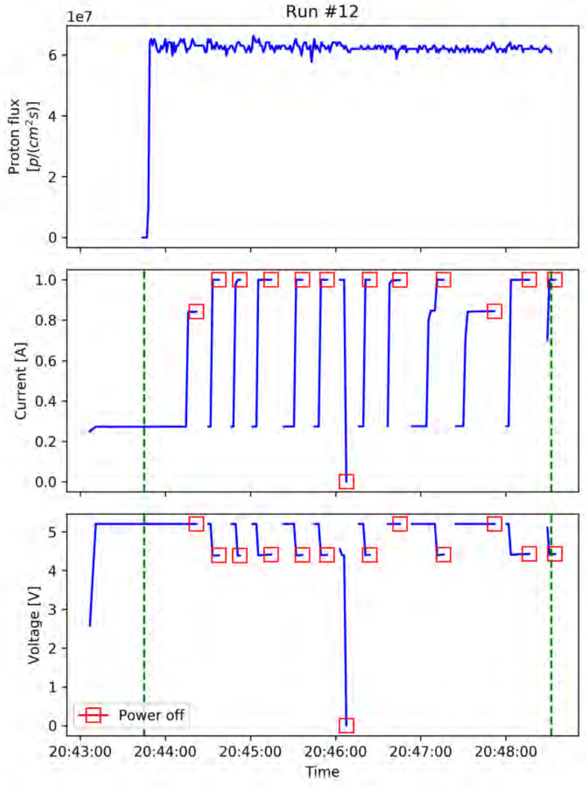


Figure 157: Run #13: STIM300 UUT-Nr.4, E(proton) = 200 MeV

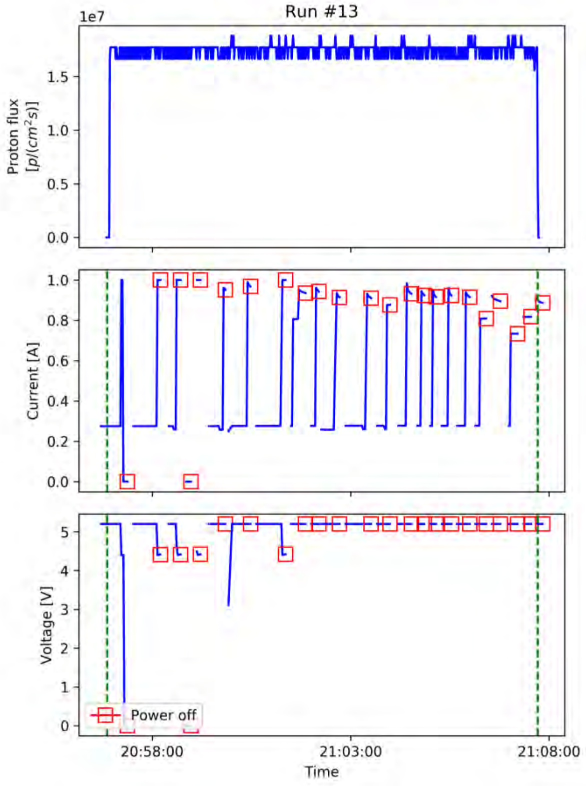


Figure 158: Run #14: STIM300 UUT-Nr.3, E(proton) = 200 MeV

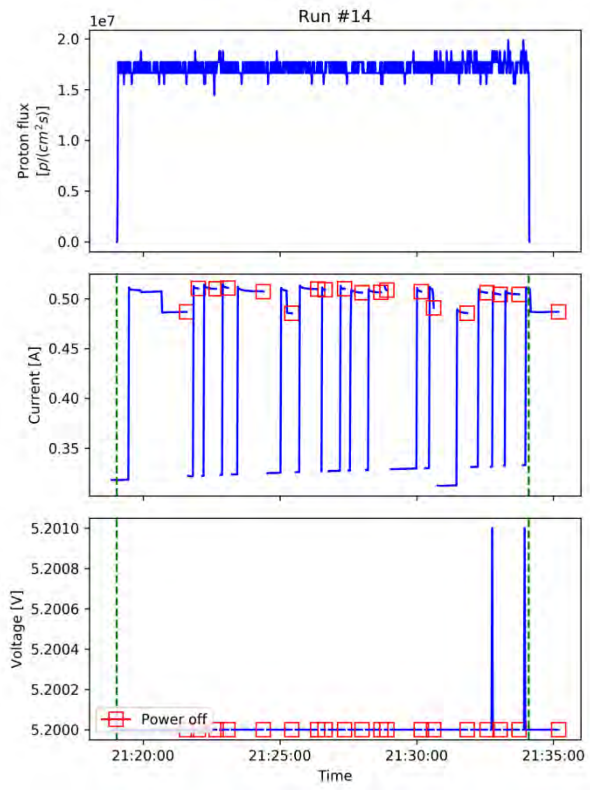


Figure 159: Run #15: STIM300 UUT-Nr.5, E(proton) = 20 MeV

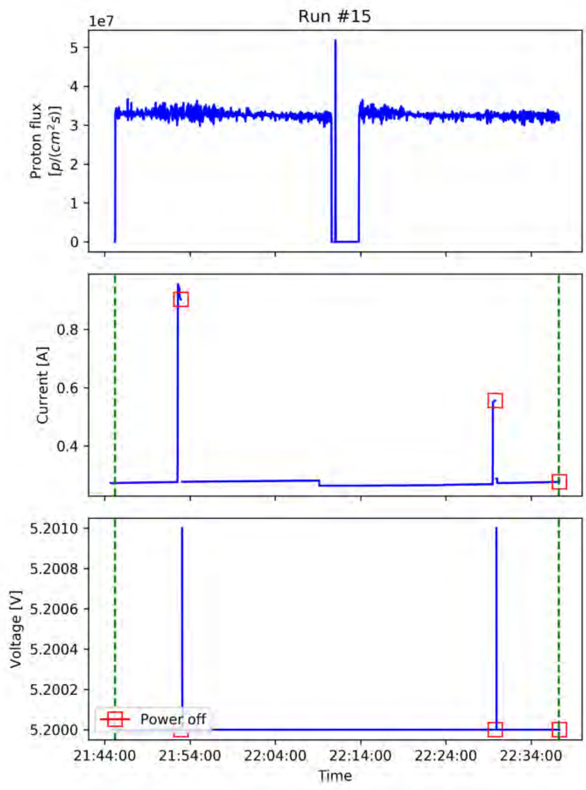


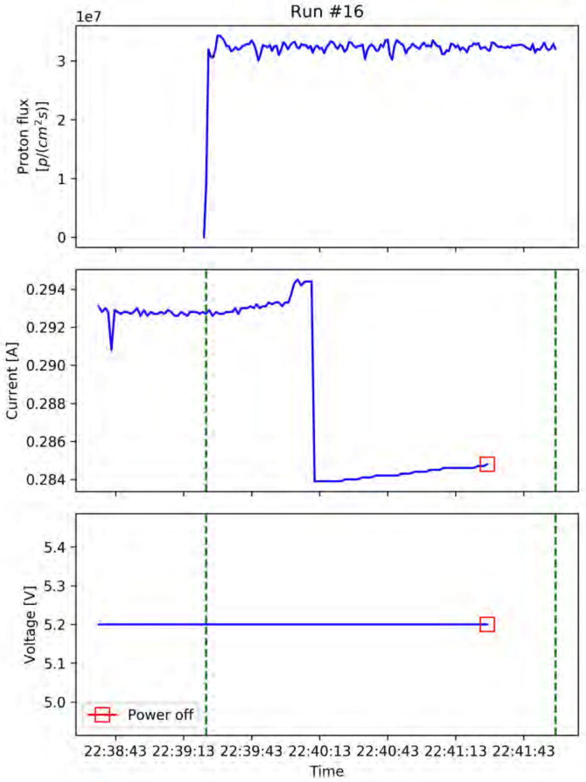
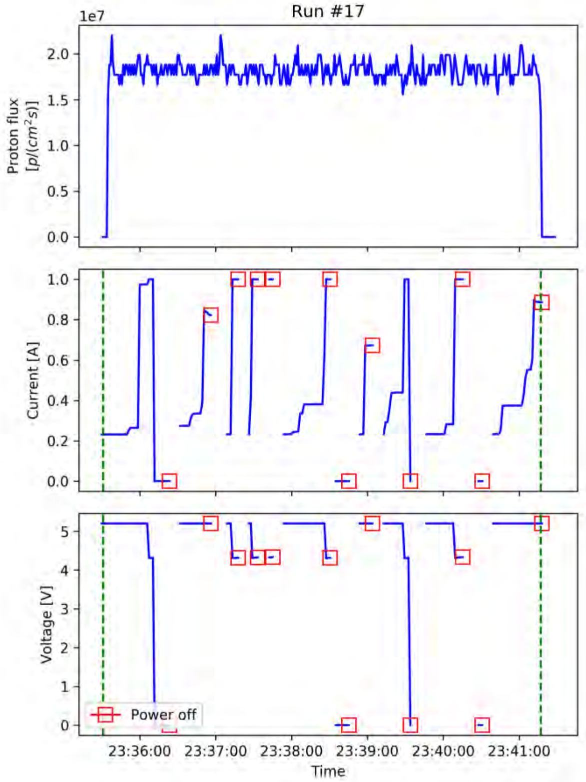
Figure 160: Run #16: STIM300 UUT-Nr.5, E(proton) = 20 MeV  Due to a power shutdown at the test laptop, premature end of power supply data	*Figure 161: Run #17: STIM210 UUT-Nr.1, E(proton) = 200 MeV* 

Figure 162: Run #18: STIM210 UUT-Nr.1, E(proton) = 200 MeV

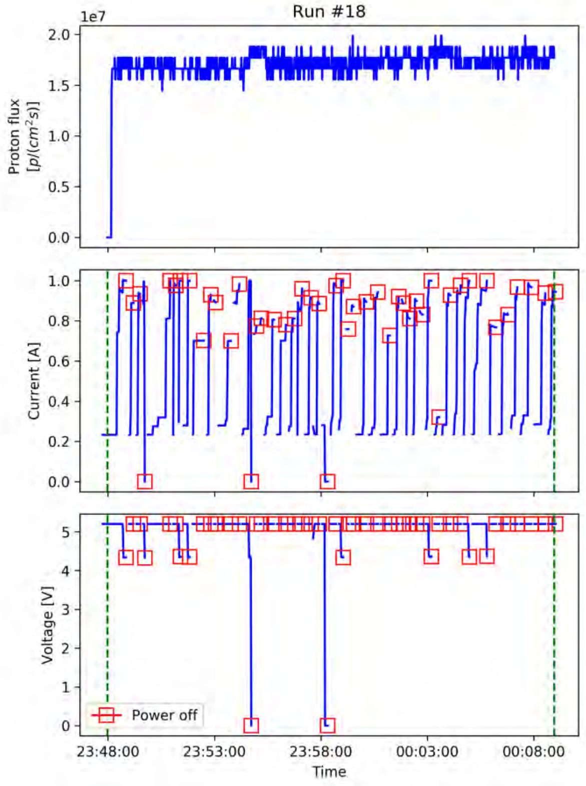


Figure 163: Run #19: STIM210 UUT-Nr.2, E(proton) = 120 MeV

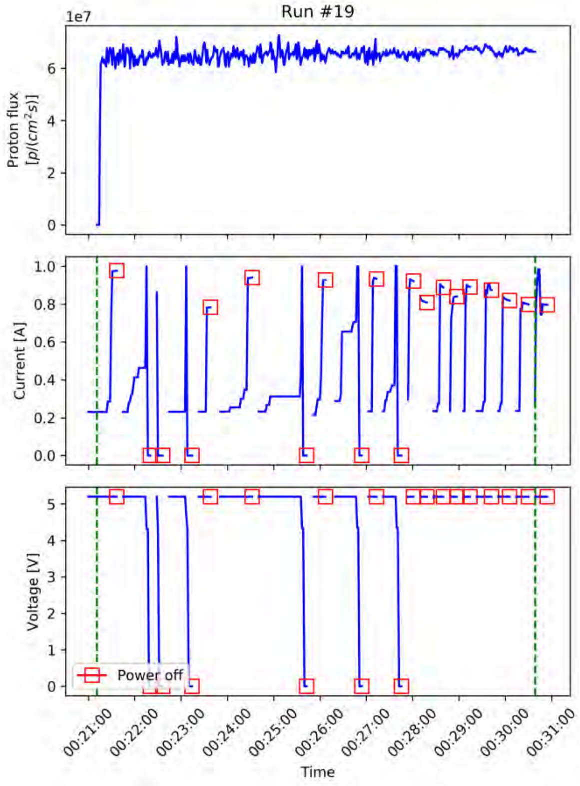


Figure 164: Run #20: STIM210 UUT-Nr.2, E(proton) = 120 MeV

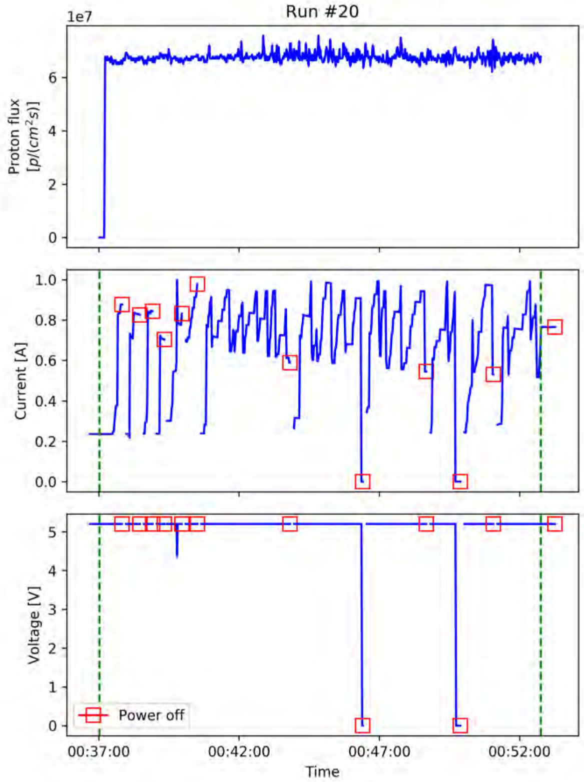
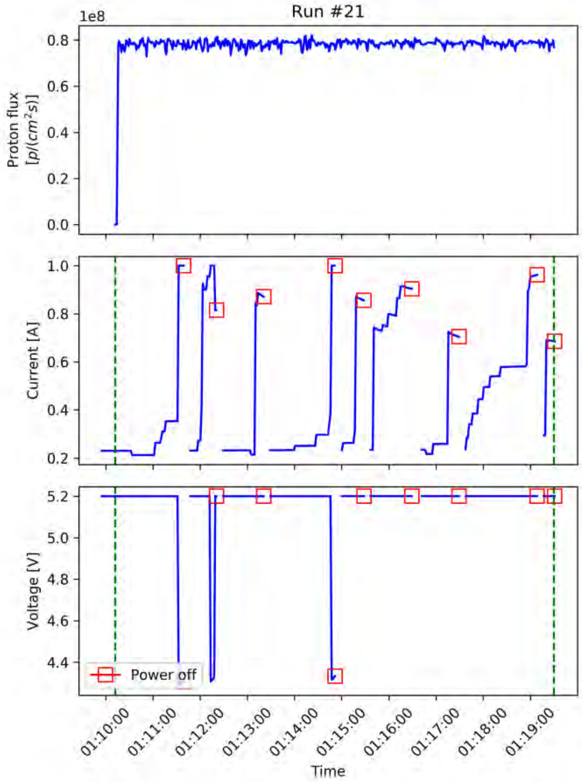


Figure 165: Run #21: STIM210 UUT-Nr.3, E(proton) = 60 MeV



Run ended due to a power shutdown at the test laptop. While at other instances this was abrupt, here the laptop froze before crashing, allowing to shut down the beam before loss of data.

Figure 166: Run #22: STIM210 UUT-Nr.3, E(proton) = 60 MeV

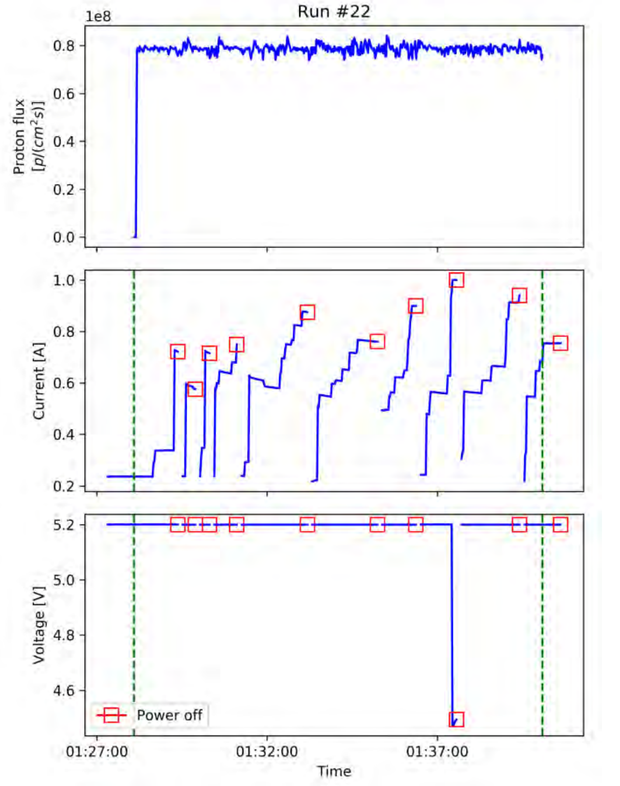


Figure 167: Run #23: STIM210 UUT-Nr.4, E(proton) = 30 MeV

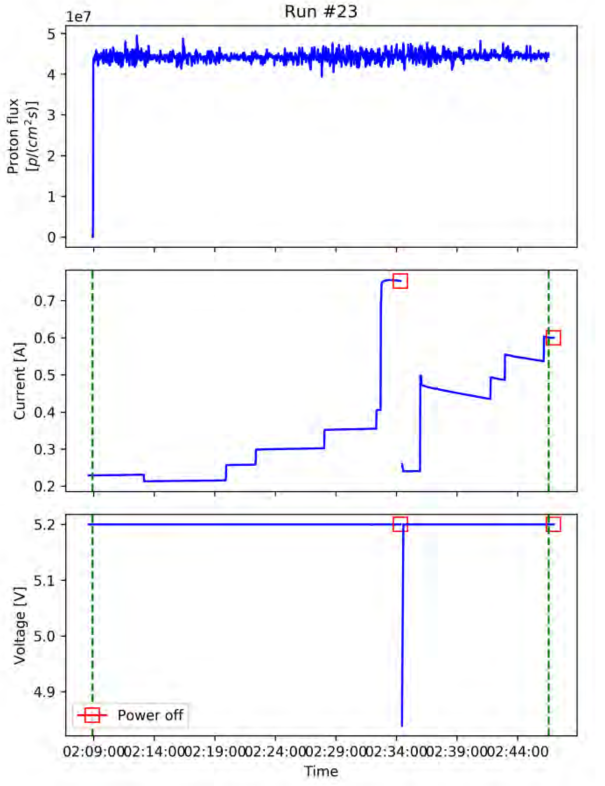
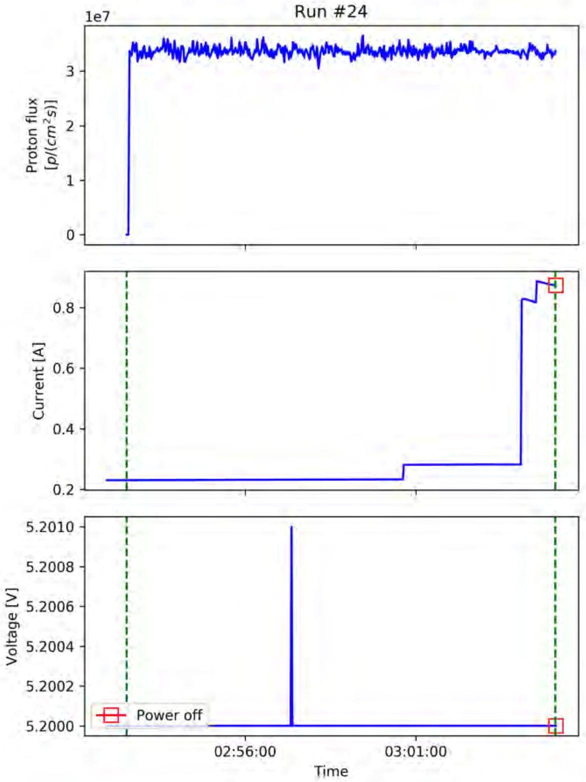
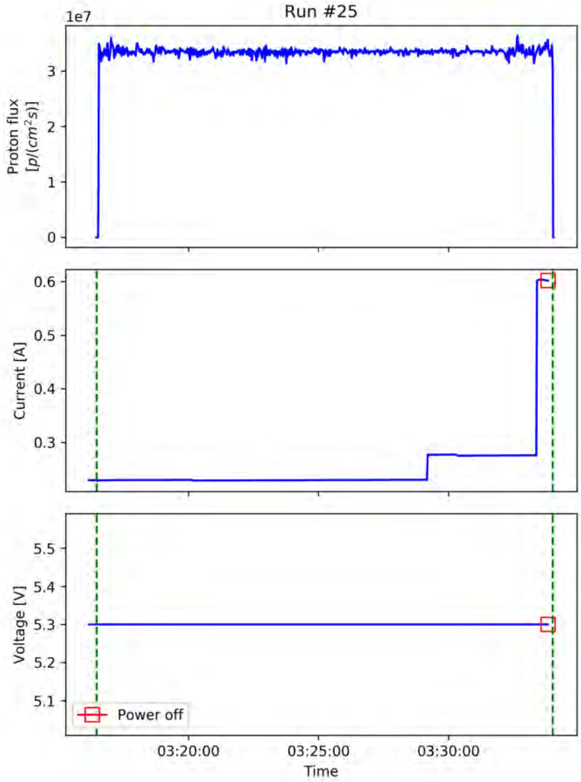


Figure 168: Run #24: STIM210 UUT-Nr.5, E(proton) = 20 MeV

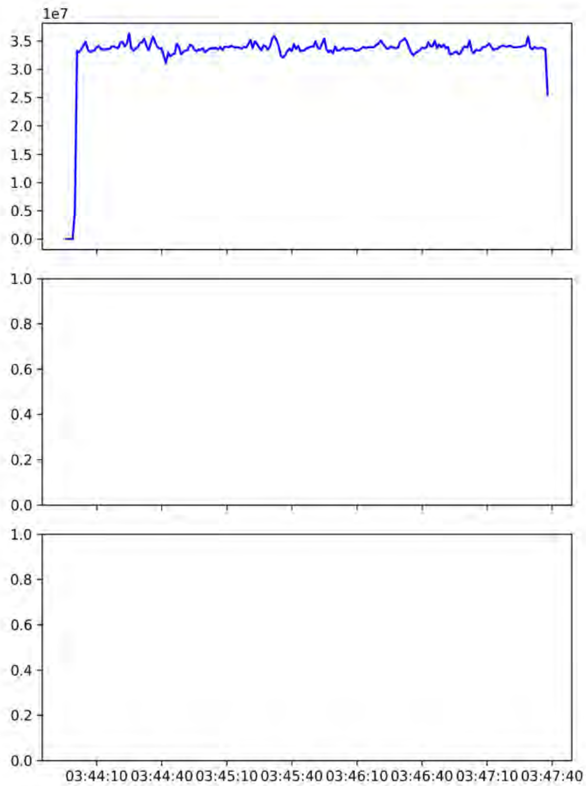


Run ended due to a power shutdown at the test laptop. While at other instances this was abrupt, here the laptop froze before crashing, allowing to shut down the beam before loss of data.

Figure 169: Run #25: STIM210 UUT-Nr.5, E(proton) = 20 MeV



Due to a power shutdown at the test laptop, premature end of power supply data

Run #26: beam was started for <1 second but UUT was not ready yet.	*Figure 170: Run #27: STIM210 UUT-Nr.5, E(proton) = 20 MeV*  Due to a power shutdown at the test laptop, no data of the currents were recorded during this run

H EMC report, STIM300

FORCE Technology Test Report

TEST Reg. no. 19

Selected EMC test of STIM 300

Performed for Sensonor AS

Project no.: 117-27645-1

FORCE Technology
Park Alle 345
2605 Brøndby
Denmark
Tlf. +45 43 25 00 00
Fax +45 43 25 00 10
www.force.dk

Title	Selected EMC test of STIM 300
Test object	STIM 300
Project no.	117-27645-1
Test period	24 September 2018 to 25 September 2018
Client	Sensonor AS Knudsrødveien 7 P.O Box 1004 3194 Horten Norway Tel.:+4733035048
Contact person	Marius Horntvedt E-mail: Marius.Horntvedt@sensonor.no
Manufacturer	Sensonor AS
Specifications	Selected parts from MIL-STD-461G Space
Results	The test object was found to be in compliance with the specifications
Test personnel	Michael Nielsen
Test site	Venlighedsvej 4, 2970 Hørsholm, Denmark

Date 12 October 2018

Project Manager

Michael Nielsen
Specialist EMC
FORCE Technology

Responsible

Per Thåstrup Jensen
Senior specialist EMC
FORCE Technology

Table of contents

1. Summary of tests

Tests	Test methods	Results
CS114, Conducted susceptibility, bulk cable injection	MIL-STD-461G CS114	Passed
RE102, Radiated emissions, electric field	MIL-STD-461G RE102	Passed

The given result is based on a shared risk principle with respect to the measurement uncertainty.

Conclusion

The test object mentioned in this report meets the requirements of the standard stated below with respect to the test listed above.

- MIL-STD-461G Space

The test results relate only to the object tested.

2. Test object and auxiliary equipment

2.1 Test object

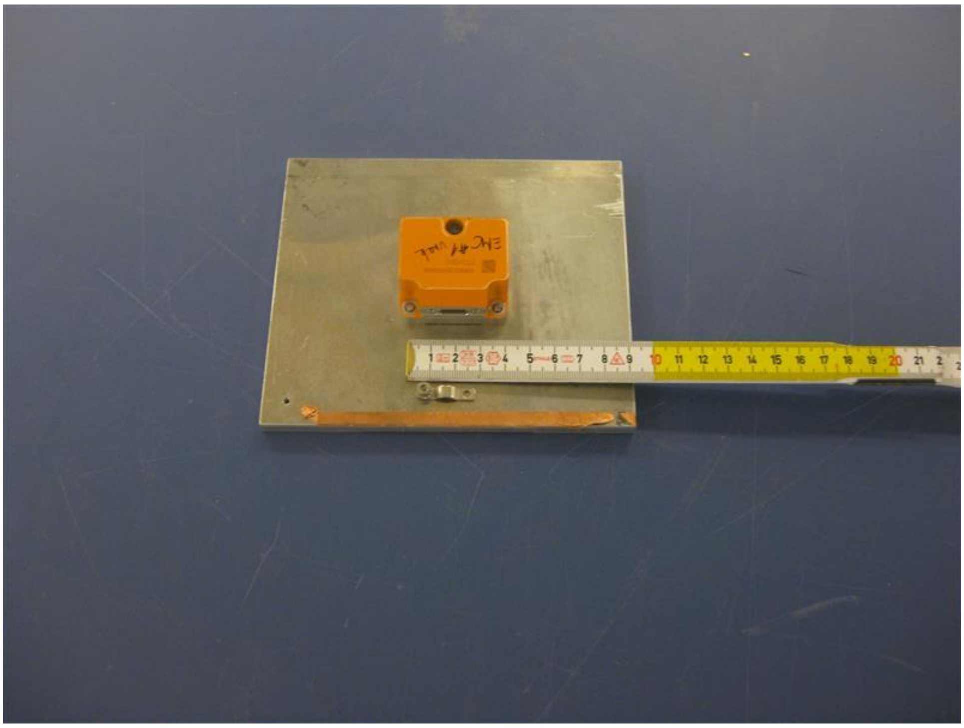


Photo 2.1.1 Test object.

Test object 2.1.1

Name of test object	STIM300
Model / type	IMU
Part no.	-
Serial no.	N25581820707832
FCC ID	-
Manufacturer	Sensonor AS
Supply voltage	5.0V
Software version	-
Hardware version	Rev G
Cycle time	-
Highest frequency generated or used	170MHz
Comment	-
Received	Date: 24 September 2018. Status: From production

2.2 Auxiliary equipment

Photo 2.2.1 Auxiliary equipment.

Auxiliary equipment 2.2.1

Name of auxiliary equipment	PC
Model / type	DC7900
Part no.	-
Serial no.	SEN 51671
FCC ID	-
Manufacturer	HP
Supply voltage	230 VAC
Highest frequency generated or used	-
Comment	Auxiliary equipment supplied by the client, who also has the responsibility for its correct function and set up.

Auxiliary equipment 2.2.2

Name of auxiliary equipment	Power Supply
Model / type	E3631A
Part no.	-
Serial no.	SEN 420568
FCC ID	-
Manufacturer	Agilent
Supply voltage	230 VAC
Highest frequency generated or used	-
Comment	Auxiliary equipment supplied by the client, who also has the responsibility for its correct function and set up.

Auxiliary equipment 2.2.3

Name of auxiliary equipment	Filter Box
Model / type	-
Part no.	-
Serial no.	-
FCC ID	-
Manufacturer	Sensonor AS
Supply voltage	-
Highest frequency generated or used	-
Comment	Auxiliary equipment supplied by the client, who also has the responsibility for its correct function and set up.

3. General test conditions

3.1 Test setup during test

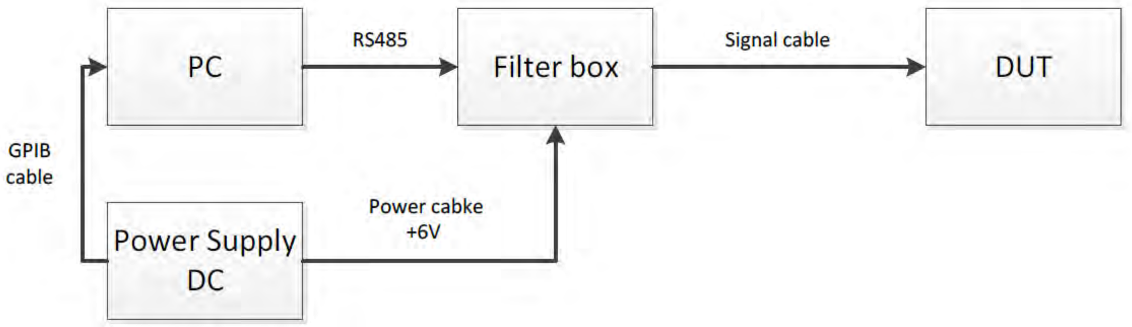


Figure 3.1.1 Block diagram of test object(s) with cables and auxiliary equipment.

Name	Cat.	Type	Max. length
RS485	Signal	Shielded	-
Signal cable	Signal	Shielded	20 m
Power cable	Power	Shielded	-
GPIB cable	Signal	Shielded	-

3.1.1 Description and intended use of test object

STIM300 is an IMU consisting of 3 high accuracy MEMS-based gyros, 3 high stability accelerometers, and 3 high stability inclinometers in a miniature package. Each axis is factory-calibrated for bias, sensitivity and compensated for temperature effects to provide high-accuracy measurements in the temperature range -40°C to +85°C. The unit runs off a single +5V supply.

3.1.2 Test modes during immunity tests

Normal Mode

3.1.3 Test modes during emission tests

Normal Mode

3.1.4 Nominal power consumption

STIM300: 300mA

3.2 Criteria for compliance during immunity test

Performance criteria according to corresponding standard were applied during immunity tests as follows:

General (for all tests)
The test object shall not become dangerous or unsafe as a result of the application of the tests.

The test object shall continue to operate as intended during and after the test without operator intervention.

The measured values shall be within the following limits:

Gyro tolerance: ±0.05°/s

Acceleration tolerance: ± 0.003g

Inclination tolerance: ± 0.004g

No errors/status byte error allowed.

The test object is not allowed to change operating mode.

During test, the test object is monitored by the PC that constantly reads values from the test object and stores them in a log file.

3.3 Test sequence

The tests described in this test report were performed in the following sequence:

1. RE102 Radiated emission, electrical field
2. CS114 Conducted susceptibility bulk cable injection

4. Test results

4.1 CS114, Conducted Susceptibility, Bulk Cable Injection

Test object	STIM300	Sheet	MIL CS114-1
Type	IMU	Project no.	117-27645-1
Serial no.	N25581820707832	Date	24-25 Sep. 2018
Client	Sensonor AS	Initials	MIN
Specification	Selected parts from MIL-STD-461G Space		

Test method Characteristics	MIL-STD-461G CS114 Bulk current injection, modulation: PM 1 kHz square	Temperature Humidity	21/21 °C 37/39 %RH
Test equipm.	EMC room 1 Hørsholm 49173 49867 29841 49558 29735 49810 49626 49503 49692 49697	Uncertainty	2 dB

Manufacturer's name of port	Frequency range [MHz]	Specified level	Level is as calibrated or the actual current level is at limit	Amplitude [dBµA]	Passed	Remarks
Signal Cable	0.01-200	Curve #4	Calibrated limit	-	Yes	

Note 1:

Criteria for compliance	See Section 3.2
Test result	The disturbances caused no malfunctions
Compliant	Yes
Comments	The current has not been measured during the test, which may have resulted in over-testing using more than the specified current limit.

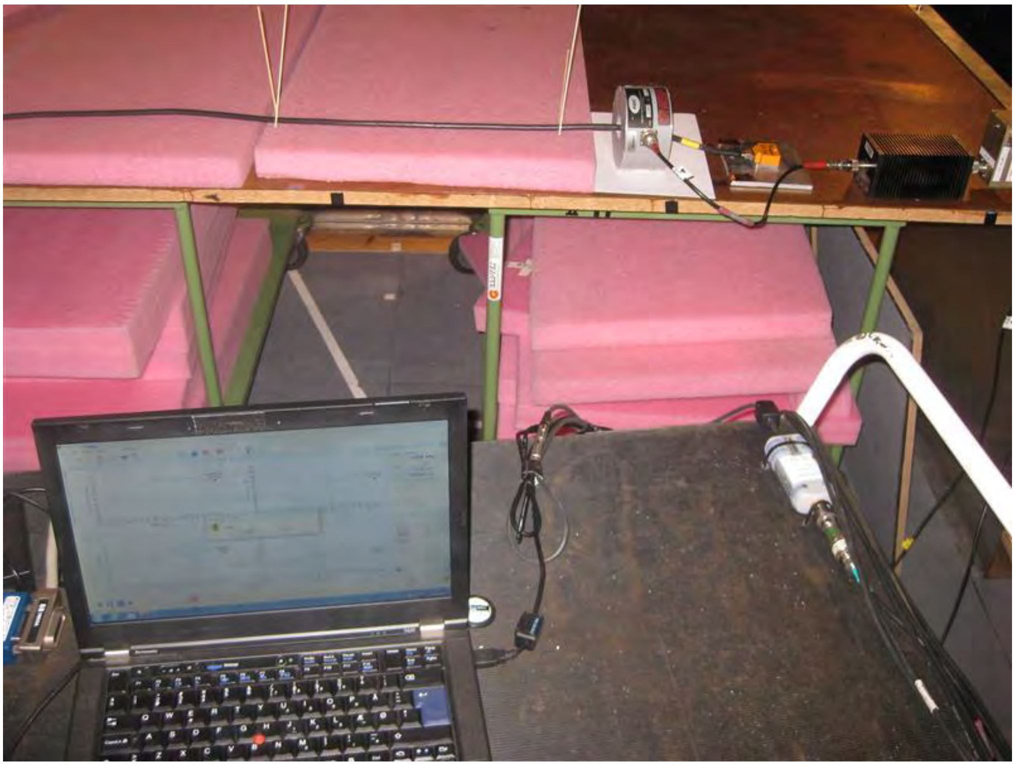


Photo 4.1.1 Test setup regarding CS114, Conducted Susceptibility, Bulk Cable Injection.

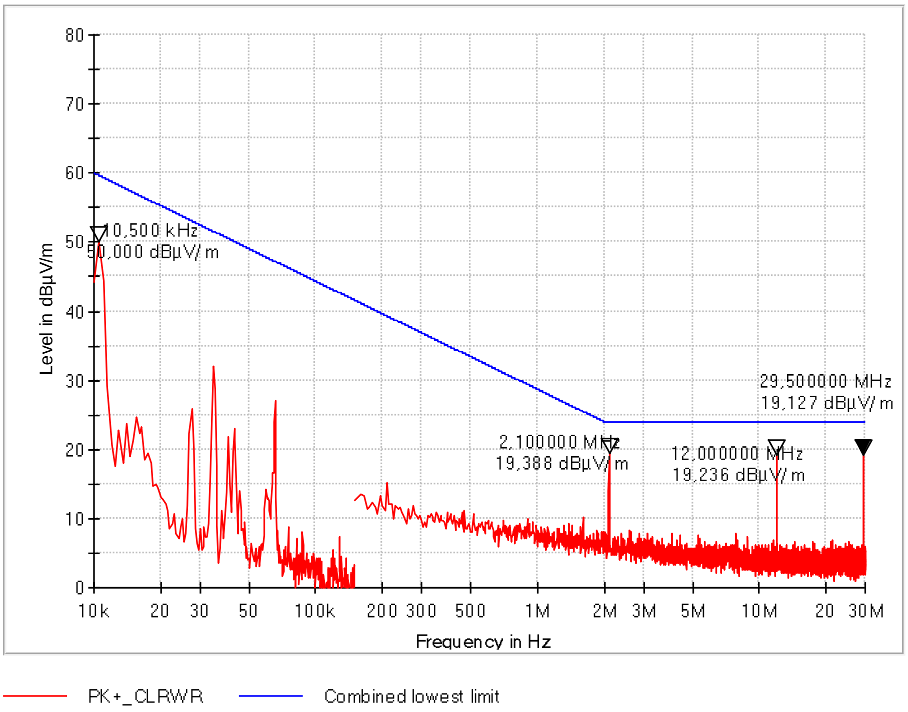
4.2 RE102, Radiated emissions, electric field

Test object	STIM300	Sheet	RE-1
Type	IMU	Project no.	117-27645-1
Serial no.	N25581820707832	Date	24 Sep. 2018
Client	Sensonor AS	Initials	MIN
Specification	Selected parts from MIL-STD-461G Space	Frequency	10 kHz – 2 GHz

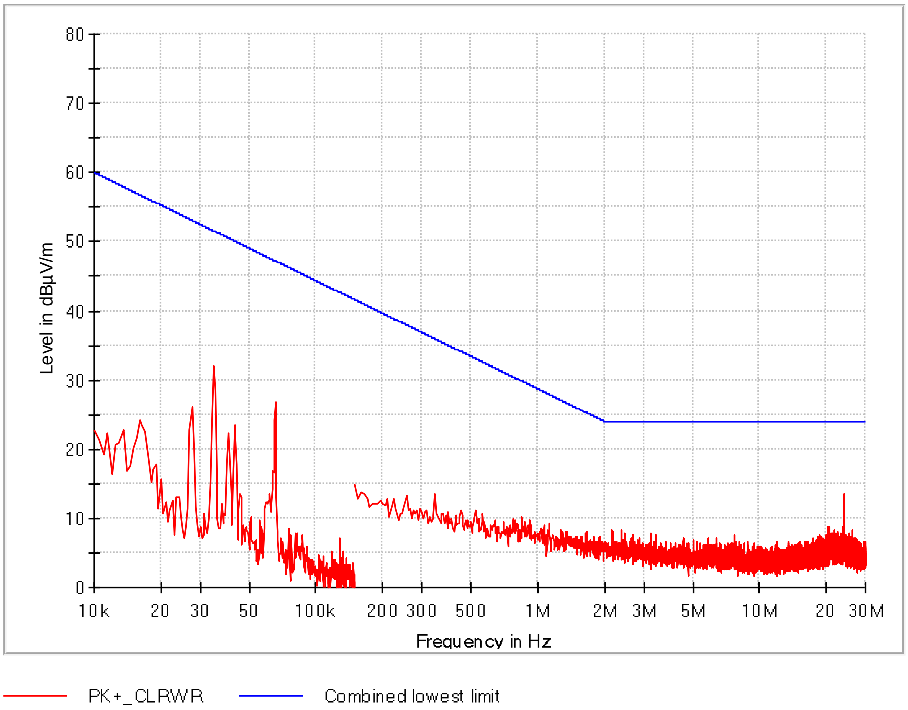
Test method Characteristics	MIL-STD-461G Antenna distance: 1 m, height: 1.2m	Temperature Humidity	21 °C 37 % RH
Detector	Peak	Bandwidth	See table
Test equipm.	EMC room 1 Hørsholm 29224 29753 29875 49729 29275 49824 49871 49872 49555	Uncertainty	3 dB

Frequency range	Bandwidth
10 – 150 kHz	1 kHz
150 kHz – 30 MHz	10 kHz
30 – 1000 MHz	100 kHz
1 – 2 GHz	1 MHz

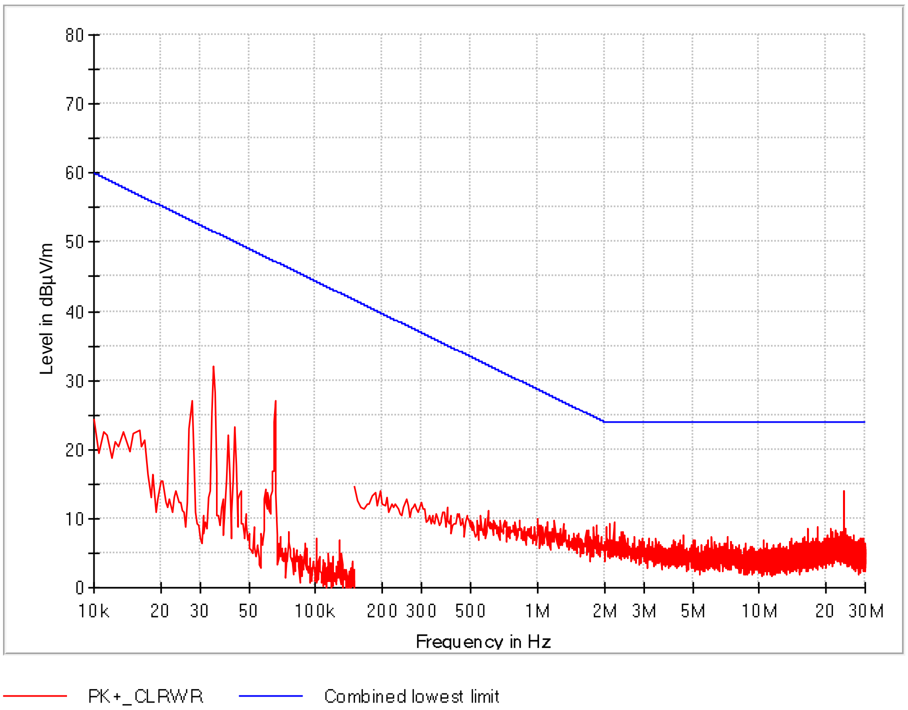
Test result	The measured field strengths are below the limit
Compliant	Yes
Comments	Plots with the text “system check” are plots that verify the test system and are done by injecting a signal of a known level and with the test object disabled and are as such not a test of the test object. No RE102 limit is stated for space equipment. The lowest limit at each frequency is chosen.



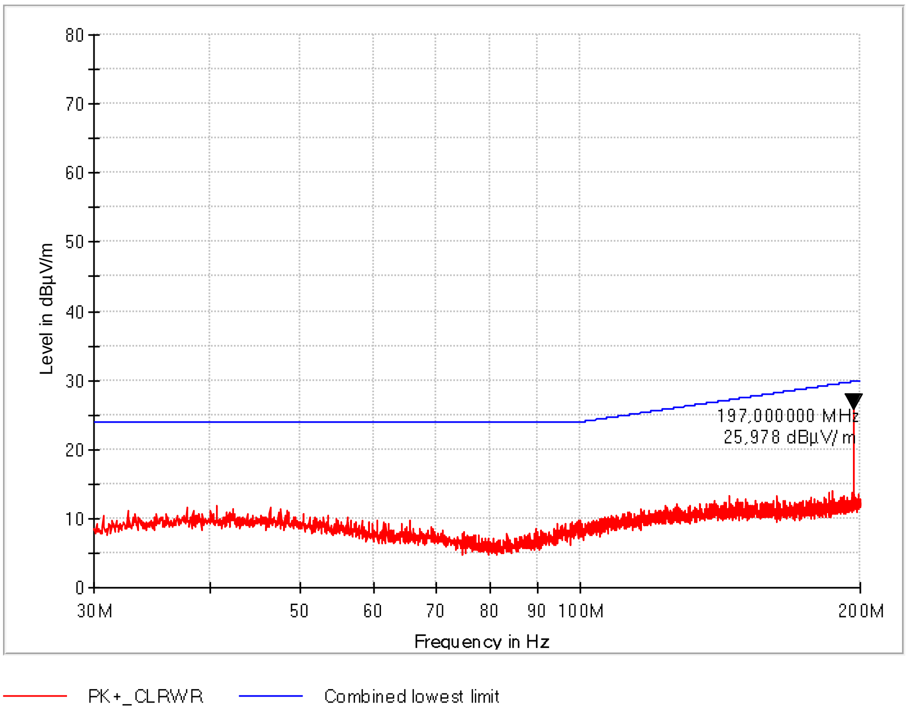
Plot 4.2.1 Test results regarding RE102, Radiated emissions, electric field. 2-30 MHz. System check 50 dBµV/m at 10.5 kHz, 18 dBµV/m at 2.1, 12 and 29.5 MHz.



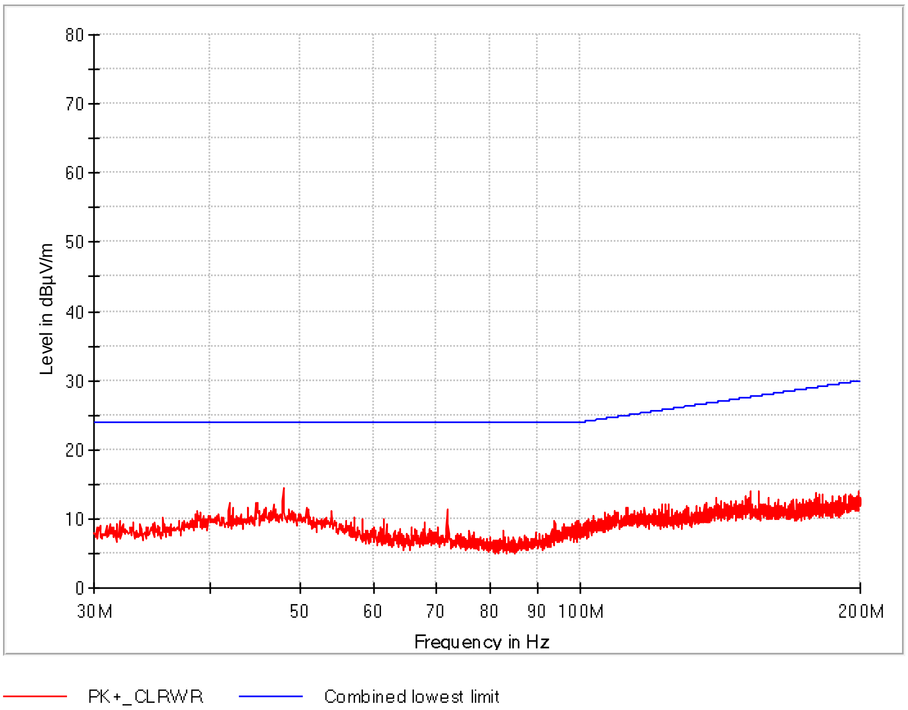
Plot 4.2.2 Test results regarding RE102, Radiated emissions, electric field. 2-30 MHz Ambient.



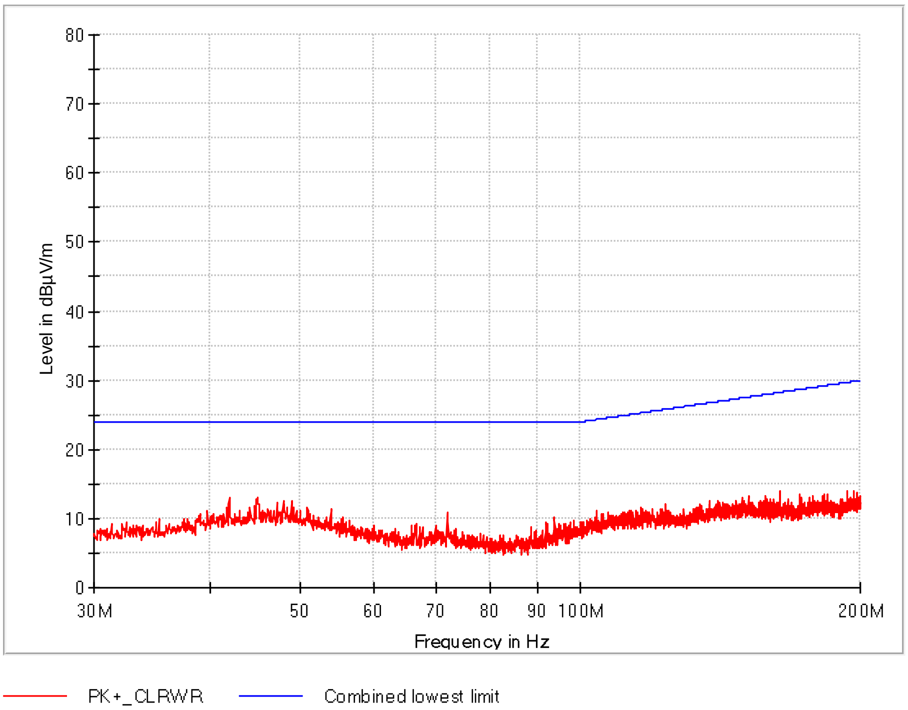
Plot 4.2.3 Test results regarding RE102, Radiated emissions, electric field. 2-30 MHz.



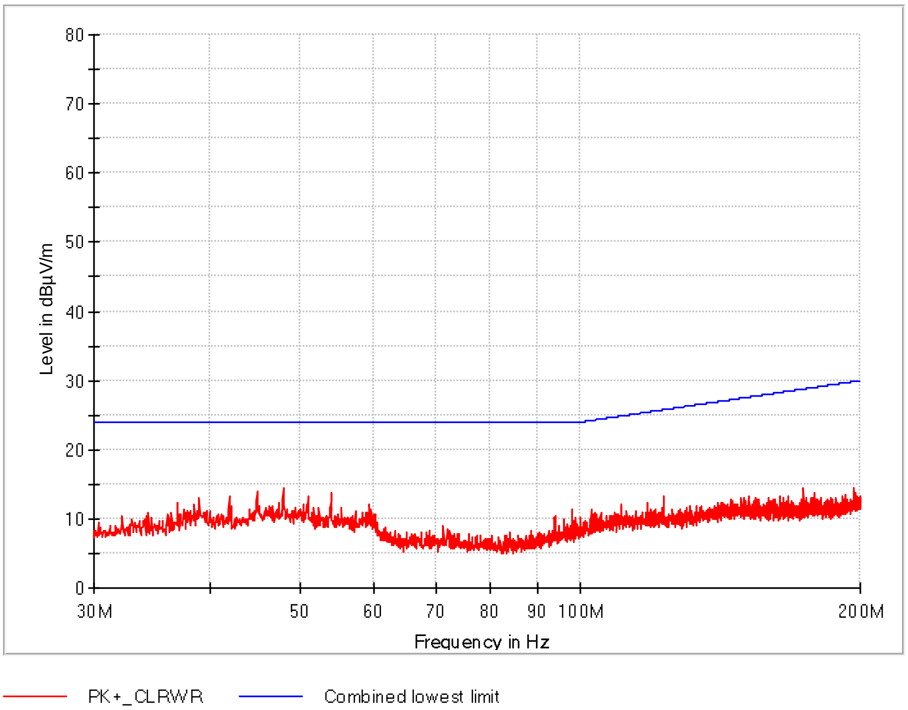
Plot 4.2.4 Test results regarding RE102, Radiated emissions, electric field. 30-200 MHz System check. 24 dBµV/m at 197 MHz.



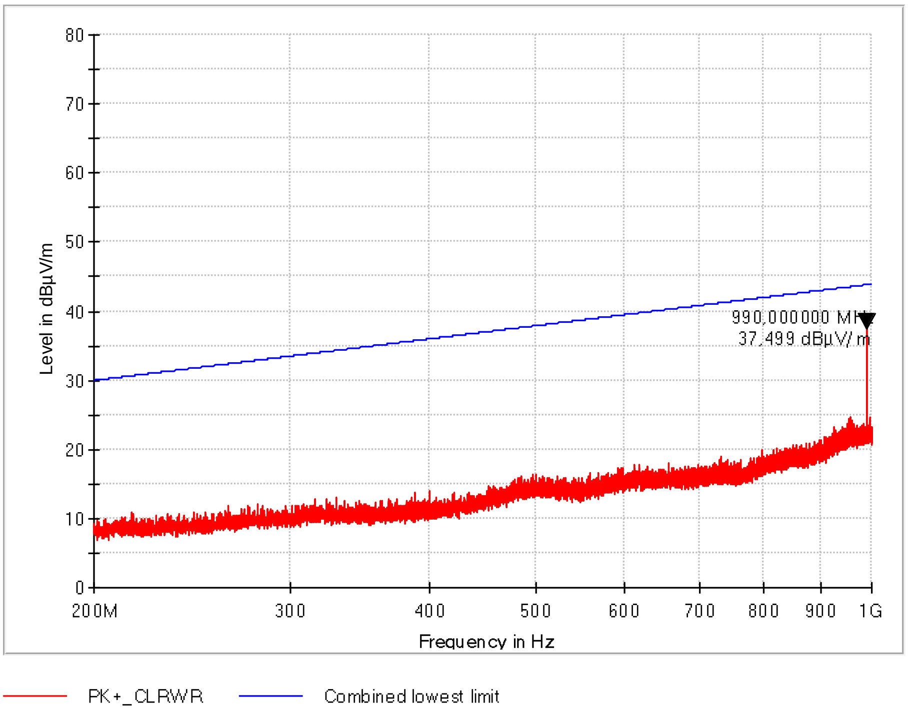
Plot 4.2.5 Test results regarding RE102, Radiated emissions, electric field.30-200 MHz Ambient.



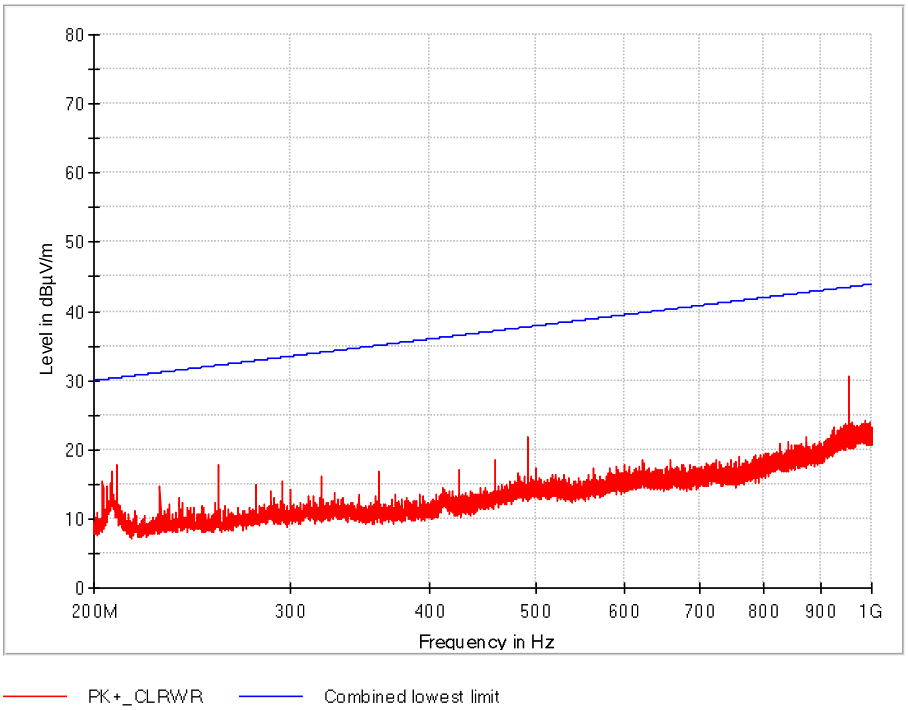
Plot 4.2.6 Test results regarding RE102, Radiated emissions, electric field. 30-200 MHz, Horizontal.



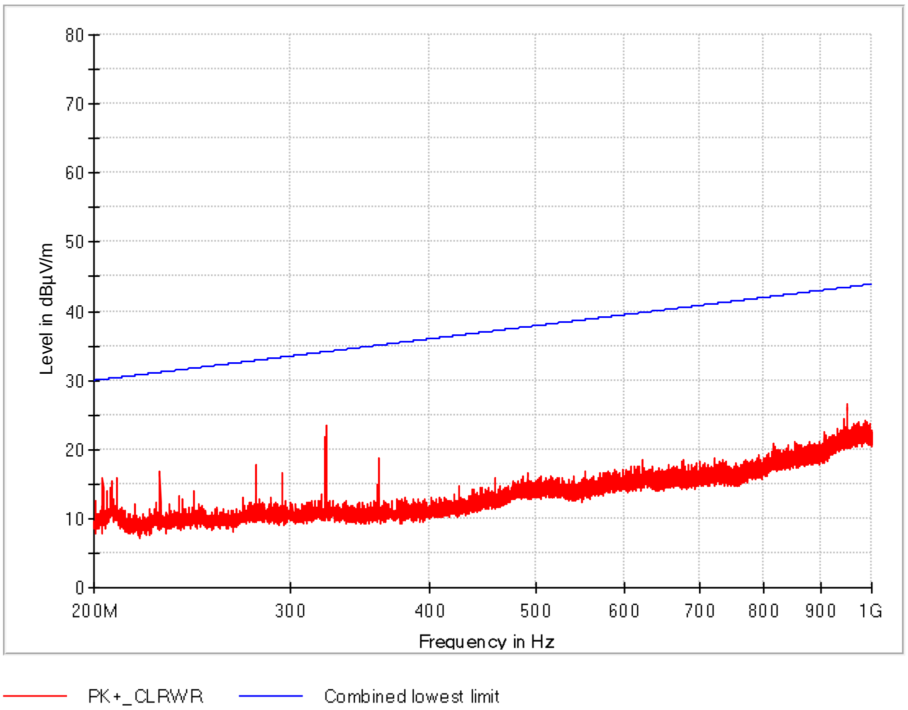
Plot 4.2.7 Test results regarding RE102, Radiated emissions, electric field.30-200 MHz Vertical.



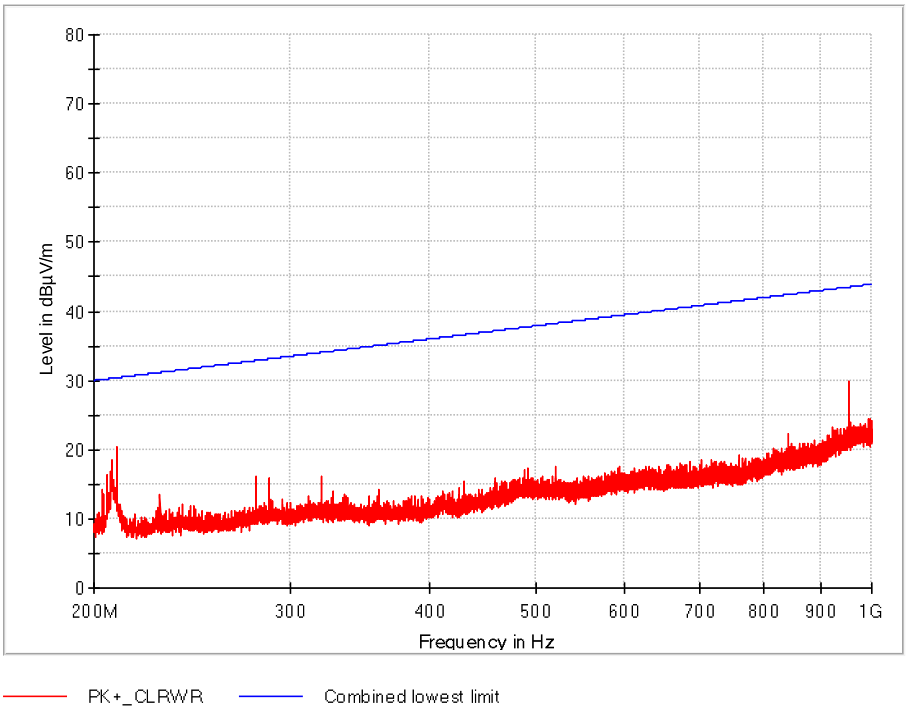
Plot 4.2.8 Test results regarding RE102, Radiated emissions, electric field. 200-1000 MHz System check. 35 dBµV/m at 990 MHz.



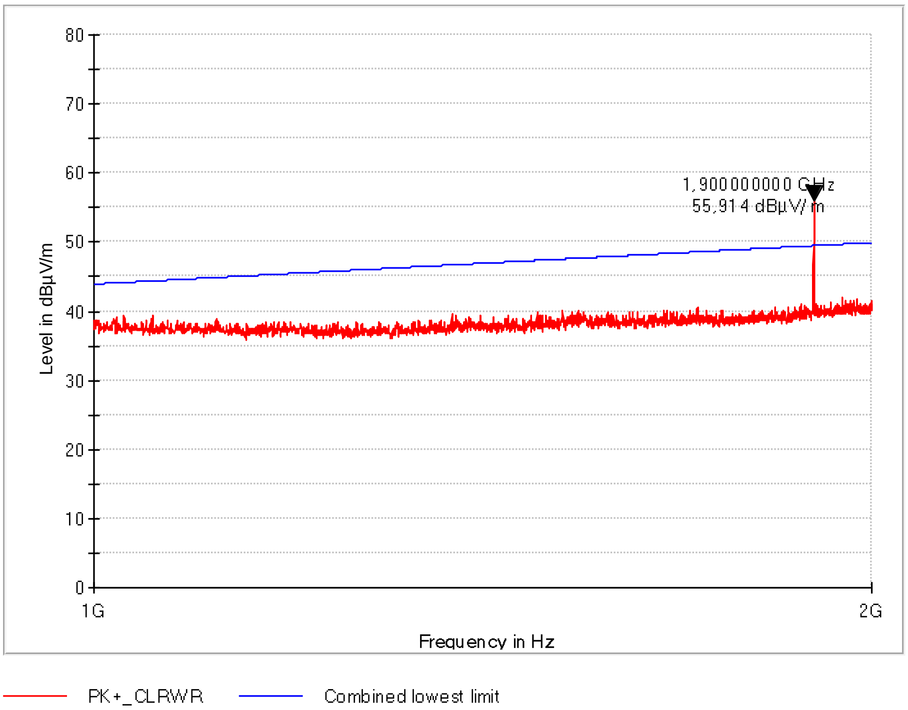
Plot 4.2.9 Test results regarding RE102, Radiated emissions, electric field.200-1000 MHz Ambient.



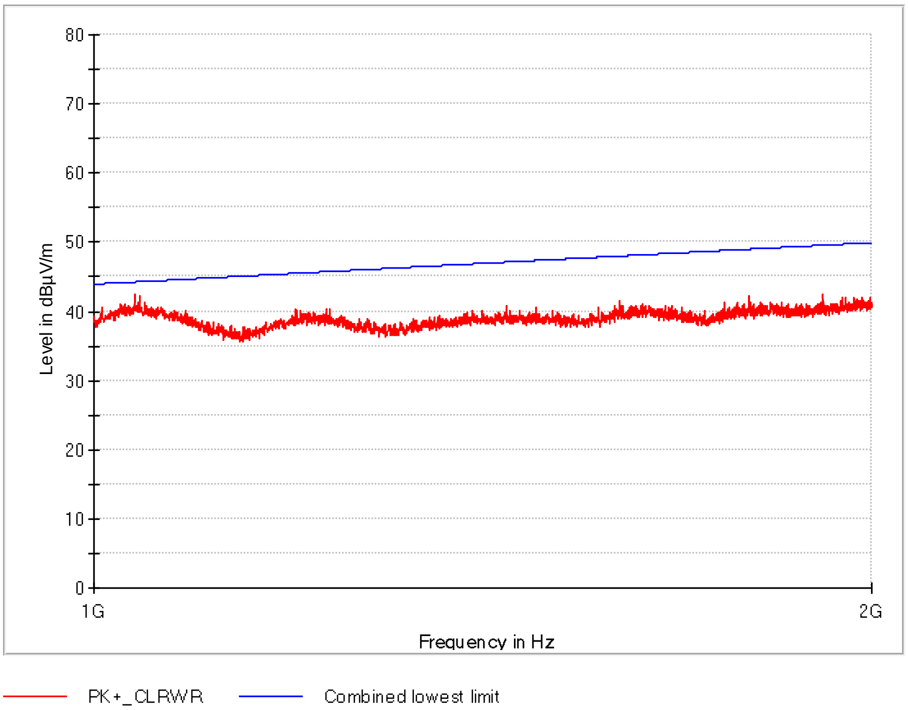
Plot 4.2.10 Test results regarding RE102, Radiated emissions, electric field. 200-1000 MHz, Horizontal.



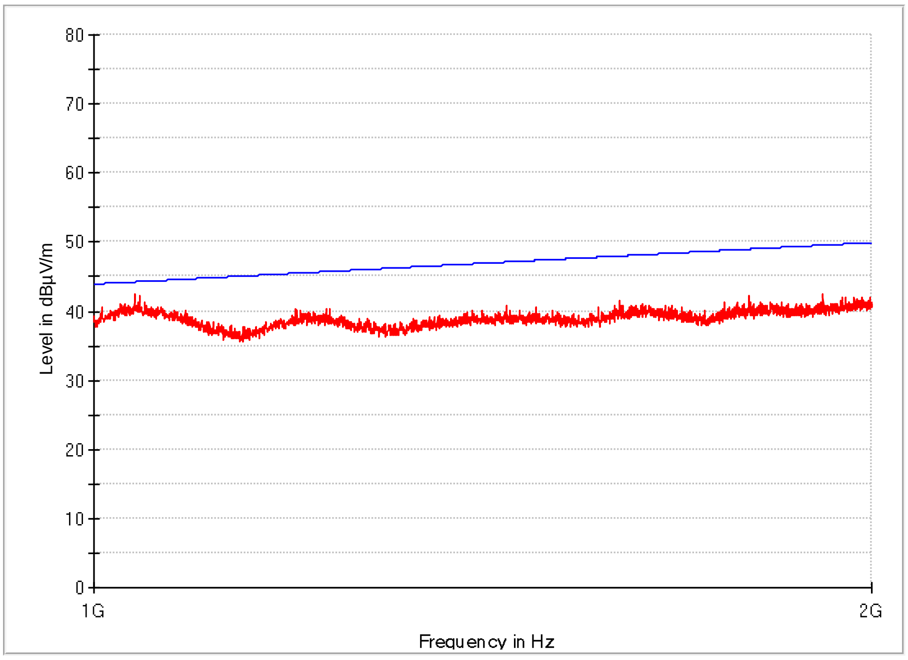
Plot 4.2.11 Test results regarding RE102, Radiated emissions, electric field.200-1000 MHz Vertical.



Plot 4.2.12 Test results regarding RE102, Radiated emissions, electric field. 1-2 GHz, System check 55 dBµV/m at 1.9 GHz.

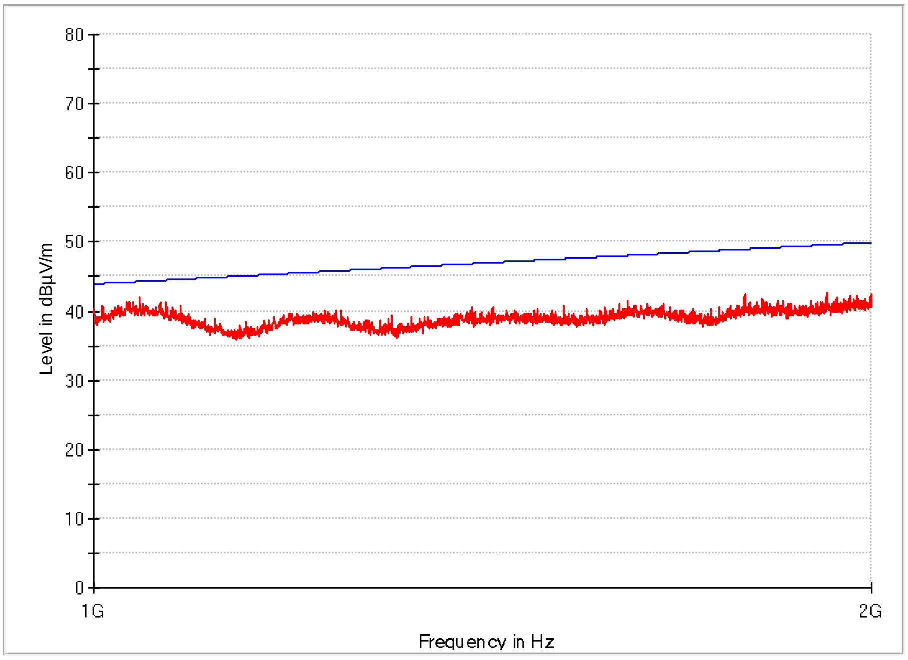


Plot 4.2.13 Test results regarding RE102, Radiated emissions, electric field. 1-2 GHz, Ambient.



PK+_CLRWR Combined lowest limit

Plot 4.2.14 Test results regarding RE102, Radiated emissions, electric field. 1-2 GHz, Horizontal.



PK+_CLRWR Combined lowest limit

Plot 4.2.15 Test results regarding RE102, Radiated emissions, electric field. 1-2 GHz, Vertical.

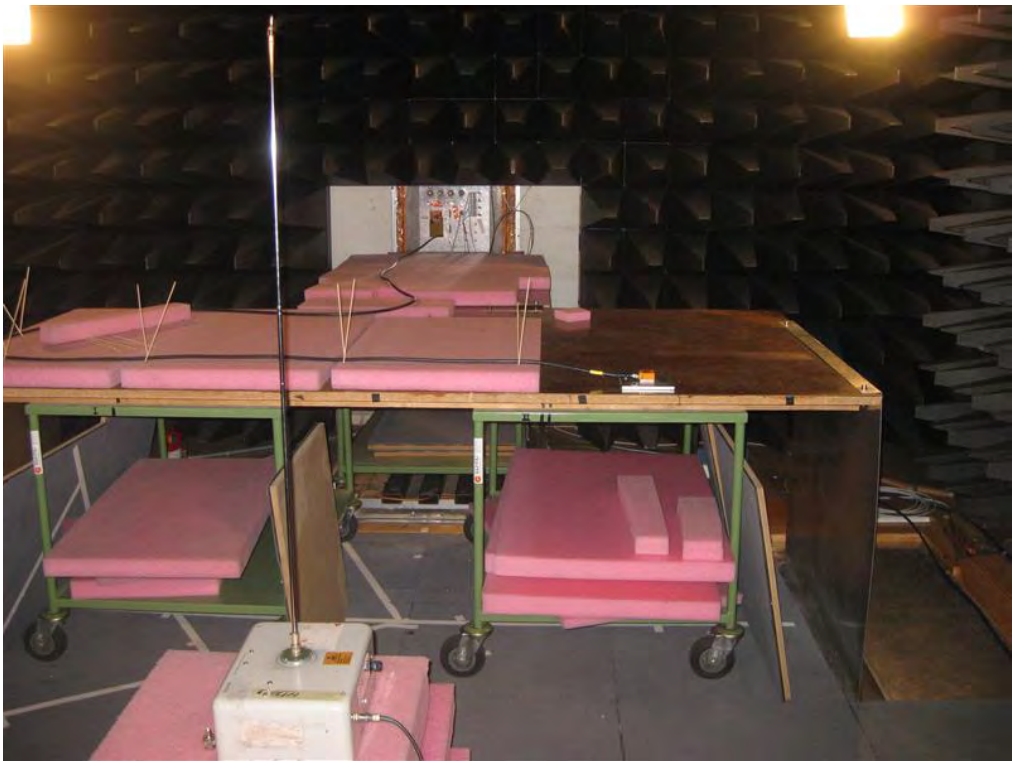


Photo 4.2.1 Test setup regarding RE102, Radiated emissions, electric field.

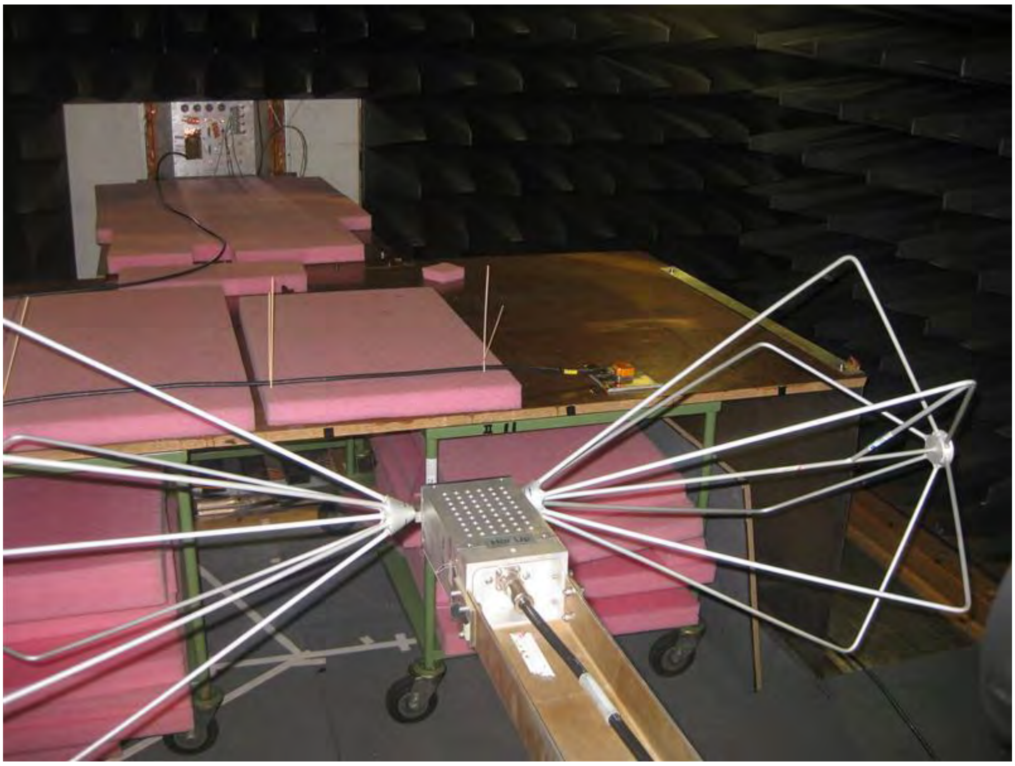


Photo 4.2.2 Test setup regarding RE102, Radiated emissions, electric field.

Photo 4.2.3 Test setup regarding RE102, Radiated emissions, electric field.

Photo 4.2.4 Test setup regarding RE102, Radiated emissions, electric field.

5. National registrations and accreditations

5.1 DANAK Accreditation

Organization:	Danish Accreditation and Metrology Fund - DANAK, see www.danak.dk and www.ilac.org
Registration Number:	19

Area Number: C

DANAK is part of ILAC (International Laboratory Accreditation Cooperation) including its MRA (Mutual Recognition Arrangement). The MRA includes the Australian NATA and Canadian SCC.

5.2 FCC Registrations

Organization:	Federal Communications Commission, USA
Registration Number:	913950
Facilities:	EMC room 2 Hørsholm (EMC-2) EMC room 3 Hørsholm (EMC-3) EMC room 4 Hørsholm (EMC-4) EMI room Hørsholm (EMC-5)

5.3 VCCI Registrations

Organization:	Voluntary Control Council for Interference by Information Technology, Japan	
Member Number:	910	
Facilities:	EMC room 3 Hørsholm (EMC-3):	C-12532 and T-11548
	EMI room Hørsholm (EMC-5):	R-11180, C-10706 T-11550 and G-10470

5.4 IC Registrations

Organization:	Industry Canada, Certification and Engineering Bureau
Registration Number:	IC4187A-5
Facilities:	EMI room Hørsholm (EMC-5)

6. List of instruments

No.	Description	Manufacturer	Type No.
29224	BROADBAND ROD ANTENNA	SINGER	95010-1
29275	LISN, MIL-STD-462/3, 50 µH	EC	10 kHz-50 MHz
29735	BULK CURRENT INJECTION PROBE, 10 kHz-400 MHz	FISCHER CUSTOM COMMUNICATIONS INC.	F-120-1
29753	BICONICAL ANTENNA, 20-300 MHz	EMCO	3109
29841	-40 dBc VOLTAGE SAMPLER, DC-100 MHz	DELTA EMC DEPT.	SAMPLER_VER_2
29875	RIDGED GUIDE HORN ANTENNA, 200 MHz - 2 GHz	EMCO	3106
49173	HF GENERATOR	Marconi	2024
49503	CABLE 0.5m BNC-BNC	SUHNER	RG223/U
49555	EMI Test Receiver, 20Hz-26GHz	ROHDE & SCHWARZ	ESU26
49558	RF POWER ATTENUATOR, 50 OHM, 6 dB, 100 W	JFW	50FH-006-100
49626	CABLE 1 m BNC-BNC	SUHNER	RG 223/U
49692	CABLE 5m BNC-BNC	SUHNER	RG 223/U
49697	CABLE 5m BNC-BNC	SUHNER	RG 223/U
49729	1-18 GHz. HORN ANTENNA.	ROHDE & SCHWARZ	4070.7000.02
49810	NRP-Z91 POWER SENSOR	ROHDE & SCHWARZ	1168.8004.02
49824	CABLE SF126EA SMA-SMA 7 m	HUBER & SUHNER	SF126EA/11SMA/11SMA/7000
49867	BROADBAND POWER AMPLIFIER, 10 kHz-250 MHz, 75 W	AMPLIFIER RESEARCH	75A250
49871	CABLE 5 M PC3.5 MALE-MALE SUCOFLEX 126	HUBER+SUHNER	SF126/11PC35/11PC35/5000MM
49872	CABLE 5 2 PC3.5 MALE-MALE SUCOFLEX 126	HUBER+SUHNER	SF126/11PC35/11PC35/2000MM

I EMC report, STIM210

FORCE Technology Test Report

TEST Reg. no. 19

Selected EMC test of STIM 210

Performed for Sensonor AS

Project no.: 117-27645-2

Page 1 of 25

FORCE Technology
Park Alle 345
2605 Brøndby
Denmark
Tlf. +45 43 25 00 00
Fax +45 43 25 00 10
www.force.dk

Title	Selected EMC test of STIM 210
Test object	STIM 210
Project no.	117-27645-2
Test period	24 September 2018 to 25 September 2018
Client	Sensonor AS Knudsrødveien 7 P.O Box 1004 3194 Horten Norway Tel.: +4733035048
Contact person	Marius Horntvedt E-mail: Marius.Horntvedt@sensonor.no
Manufacturer	Sensonor AS
Specifications	Selected parts from MIL-STD-461G Space
Results	The test object was found to be in compliance with the specifications
Test personnel	Michael Nielsen
Test site	Venlighedsvej 4, 2970 Hørsholm, Denmark

Date 10 October 2018

Project Manager

Michael Nielsen
Specialist EMC
FORCE Technology

Responsible

Per Thåstrup Jensen
Senior specialist EMC
FORCE Technology

Table of contents Page

1. Summary of tests

Tests	**Test methods**	**Results**
CS114, Conducted susceptibility, bulk cable injection	MIL-STD-461G CS114	Passed
RE102, Radiated emissions, electric field	MIL-STD-461G RE102	Passed

The given result is based on a shared risk principle with respect to the measurement uncertainty.

Conclusion

The test object mentioned in this report meets the requirements of the standard stated below, with respect to the test listed above.

- MIL-STD-461G Space

The test results relate only to the object tested.

2. Test object and auxiliary equipment

2.1 Test object

Photo 2.1.1 Test object.

Test object 2.1.1

Name of test object	STIM210
Model / type	MEMS Gyro module
Part no.	-
Serial no.	N25581824753909
FCC ID	-
Manufacturer	Sensonor AS
Supply voltage	5.0V
Software version	-
Hardware version	Rev H
Cycle time	-
Highest frequency generated or used	120MHz
Comment	-
Received	Date: 24 September 2018. Status: From production

2.2 Auxiliary equipment

Photo 2.2.1 Auxiliary equipment.

Auxiliary equipment 2.2.1

Name of auxiliary equipment	PC
Model / type	DC7900
Part no.	-
Serial no.	SEN 51671
FCC ID	-
Manufacturer	HP
Supply voltage	230 VAC
Highest frequency generated or used	-
Comment	Auxiliary equipment supplied by the client, who also has the responsibility for its correct function and set up.

Auxiliary equipment 2.2.2

Name of auxiliary equipment	Power Supply
Model / type	E3631A
Part no.	-
Serial no.	SEN 420568
FCC ID	-
Manufacturer	Agilent
Supply voltage	230 VAC
Highest frequency generated or used	-
Comment	Auxiliary equipment supplied by the client, who also has the responsibility for its correct function and set up.

Auxiliary equipment 2.2.3

Name of auxiliary equipment	Filter Box
Model / type	-
Part no.	-
Serial no.	-
FCC ID	-
Manufacturer	Sensonor AS
Supply voltage	-
Highest frequency generated or used	-
Comment	Auxiliary equipment supplied by the client, who also has the responsibility for its correct function and set up.

3. General test conditions

3.1 Test setup during test

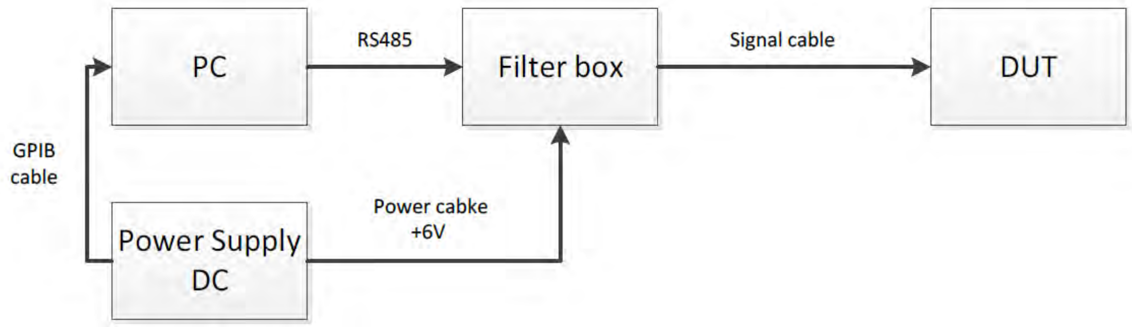


Figure 3.1.1 Block diagram of test object(s) with cables and auxiliary equipment.

Name	Cat.	Type	Max. length
RS485	Signal	Shielded	-
Signal cable	Signal	Shielded	20 m
Power cable	Power	Shielded	-
GPIB cable	Signal	Shielded	-

3.1.1 Description and intended use of test object

STIM210 is a cluster of 1, 2 or 3 high accuracy MEMS-based gyros in a miniature package. Any configuration of axes can be provided. Each axis is factory-calibrated for bias sensitivity and compensated for temperature effects to provide high-accuracy measurements in the temperature range -40°C to +85°C. The unit runs off a single +5V supply.

3.1.2 Test modes during immunity tests

Normal Mode

3.1.3 Test modes during emission tests

Normal Mode

3.1.4 Nominal power consumption

STIM210: 250mA

3.2 Criteria for compliance during immunity test

Performance criteria according to corresponding standard were applied during immunity tests as follows:

General (for all tests)
The test object shall not become dangerous or unsafe as a result of the application of the tests.

The test object shall continue to operate as intended during and after the test without operator intervention.

The measured values shall be within the following limits:

Gyro tolerance: ±0.05°/s

No errors/status byte error allowed.

The test object is not allowed to change operating mode.

During test, the test object is monitored by the PC, which constantly reads values from the test object and stores them in a log file.

3.3 Test sequence

The tests described in this test report were performed in the following sequence:

1. RE102 Radiated emission, electrical field
2. CS114 Conducted susceptibility bulk cable injection

4. Test results

4.1 CS114, Conducted Susceptibility, Bulk Cable Injection

Test object	STIM210	Sheet	MIL CS114-1
Type	MEMS Gyro module	Project no.	117-27645-2
Serial no.	N25581824753909	Date	24 & 25 Sep. 2018
Client	Sensonor AS	Initials	MIN
Specification	Selected parts from MIL-STD-461G Space		

Test method Characteristics	MIL-STD-461G CS114 Bulk current injection, modulation: PM 1 kHz square	Temperature Humidity	21/21 °C 37/39 %RH
Test equipm.	EMC room 1 Hørsholm 49173 49867 29841 49558 29735 49810 49626 49503 49692 49697	Uncertainty	2 dB

Manufacturer's name of port	Frequency range [MHz]	Specified level	Level is as calibrated or the actual current level is at limit	Amplitude [dBµA]	Passed	Remarks
Signal Cable	0.01-200	Curve #4	Calibrated limit	-	Yes	
Power part of signal cable	0.01-200	Curve #3	Calibrated limit	-	Yes	
Power forward part of signal cable	0.01-200	Curve #3	Calibrated limit	-	Yes	
Note 1:						

Criteria for compliance — See Section 3.2

Test result — The disturbances caused no malfunctions

Compliant — Yes

Comments — The current has not been measured during the test, which may have resulted in over-testing using more than the specified current limit.

Requirement for space is Curve 3. The combined cable is tested at a higher level due to client request.

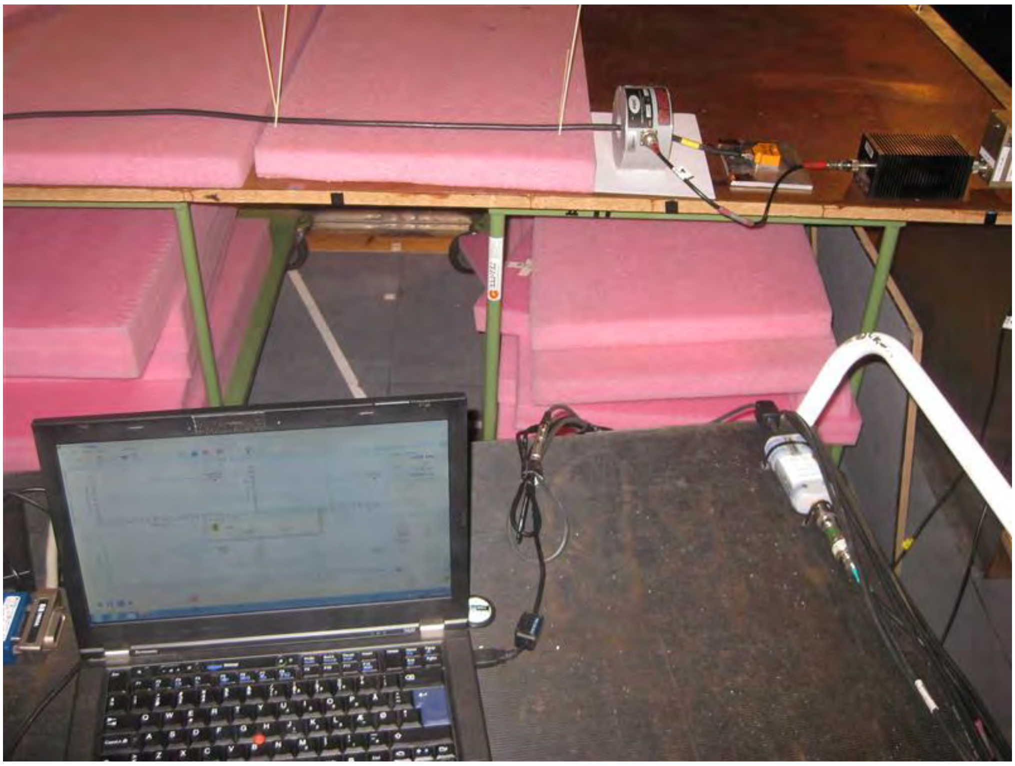


Photo 4.1.1 Test setup regarding CS114, Conducted Susceptibility, Bulk Cable Injection.

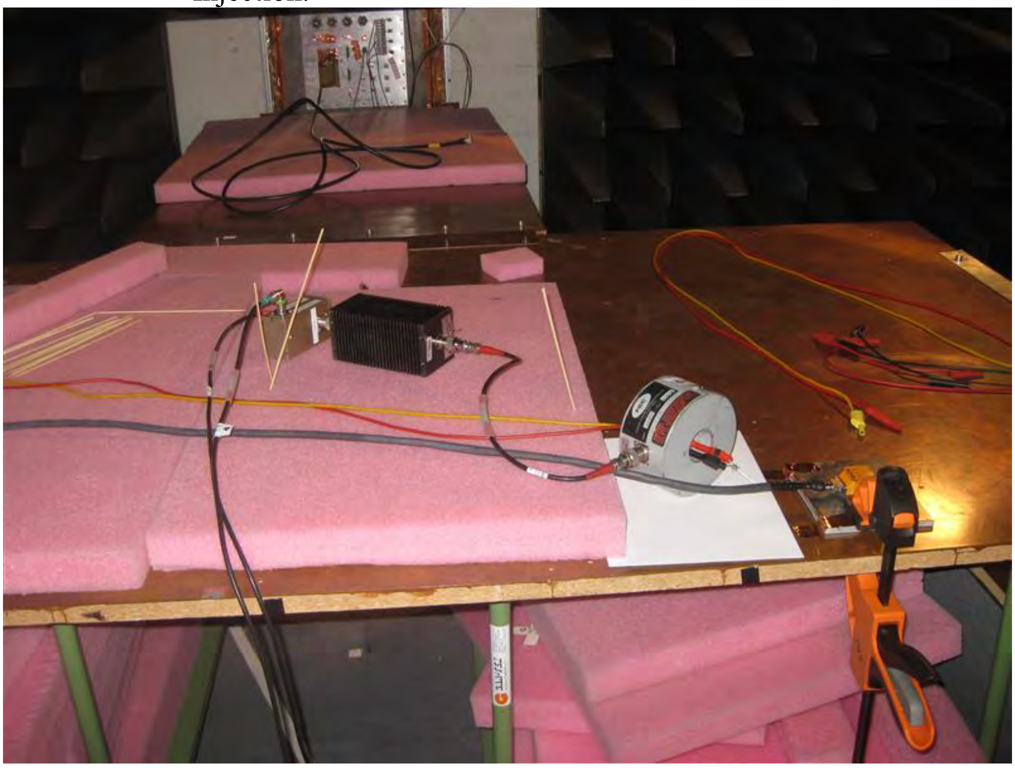


Photo 4.1.2 Test setup regarding CS114, Conducted Susceptibility, Bulk Cable Injection.

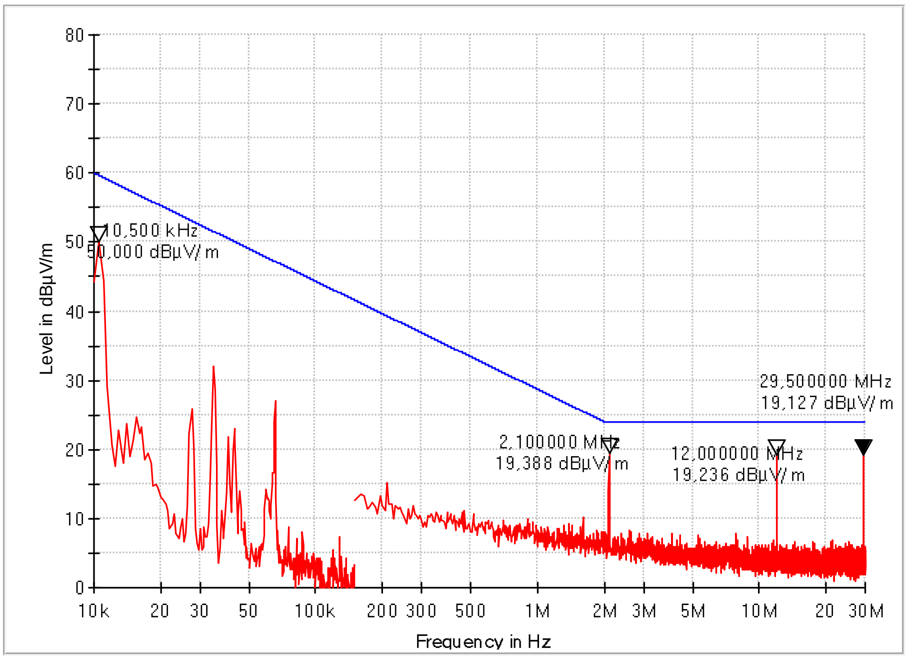
4.2 RE102, Radiated emissions, electric field

Test object	STIM210	Sheet	RE-1
Type	MEMS Gyro module	Project no.	117-27645-2
Serial no.	N25581824753909	Date	24 Sep. 2018
Client	Sensonor AS	Initials	MIN
Specification	Selected parts from MIL-STD-461G Space	Frequency	10 kHz – 2 GHz

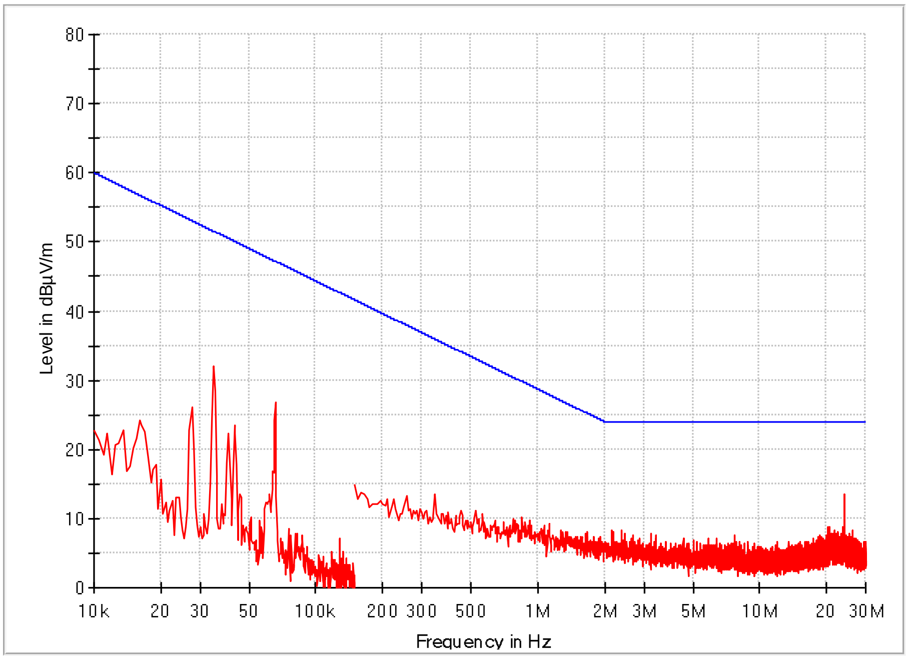
Test method Characteristics	MIL-STD-461G Antenna distance: 1 m, height: 1.2m	Temperature Humidity	21 °C 37 % RH
Detector	Peak	Bandwidth	See table
Test equipm.	EMC room 1 Hørsholm 29224 29753 29875 49729 29275 49824 49871 49872 49555	Uncertainty	3 dB

Frequency range	Bandwidth
10 – 150 kHz	1 kHz
150 kHz – 30 MHz	10 kHz
30 – 1000 MHz	100 kHz
1 – 2 GHz	1 MHz

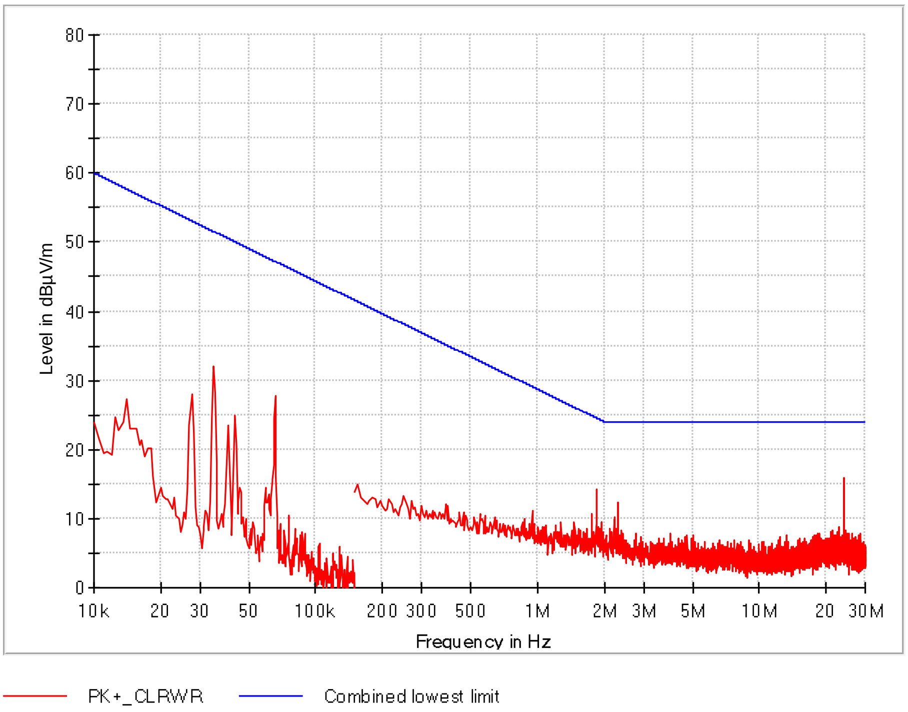
Test result	The measured field strengths are below the limit
Compliant	Yes
Comments	Plots with the text “system check” are plots that verify the test system and are done by injecting a signal of a known level and with the test object disabled and are as such not a test of the test object. No RE102 limit is stated for space equipment. The lowest limit is at each frequency is chosen.



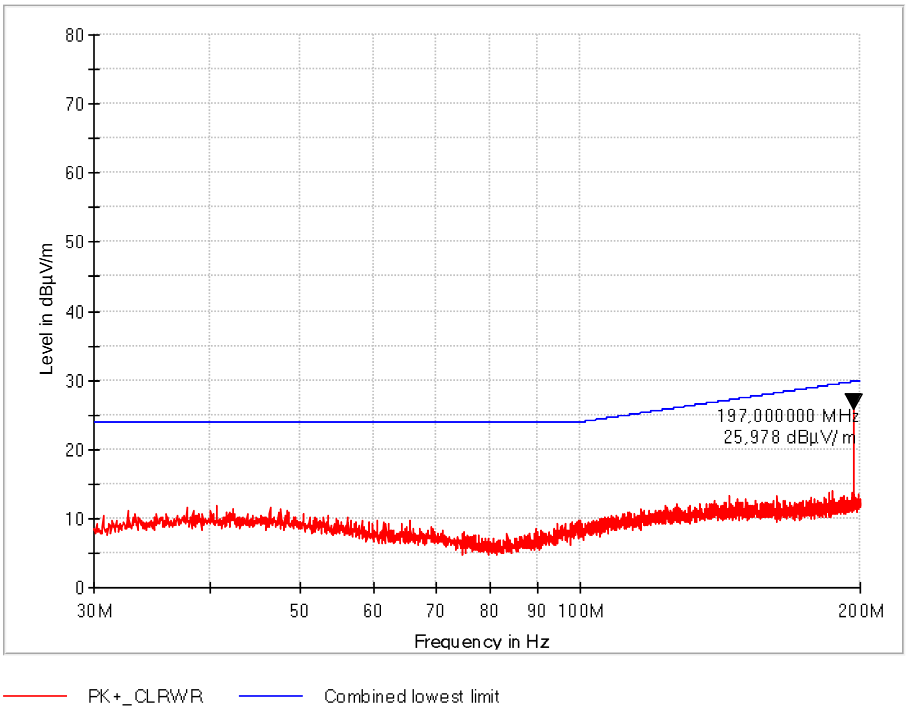
Plot 4.2.1 Test results regarding RE102, Radiated emissions, electric field. 2-30 MHz. System check 50 dBµV/m at 10.5 kHz, 18 dBµV/m at 2.1, 12 and 29.5 MHz.



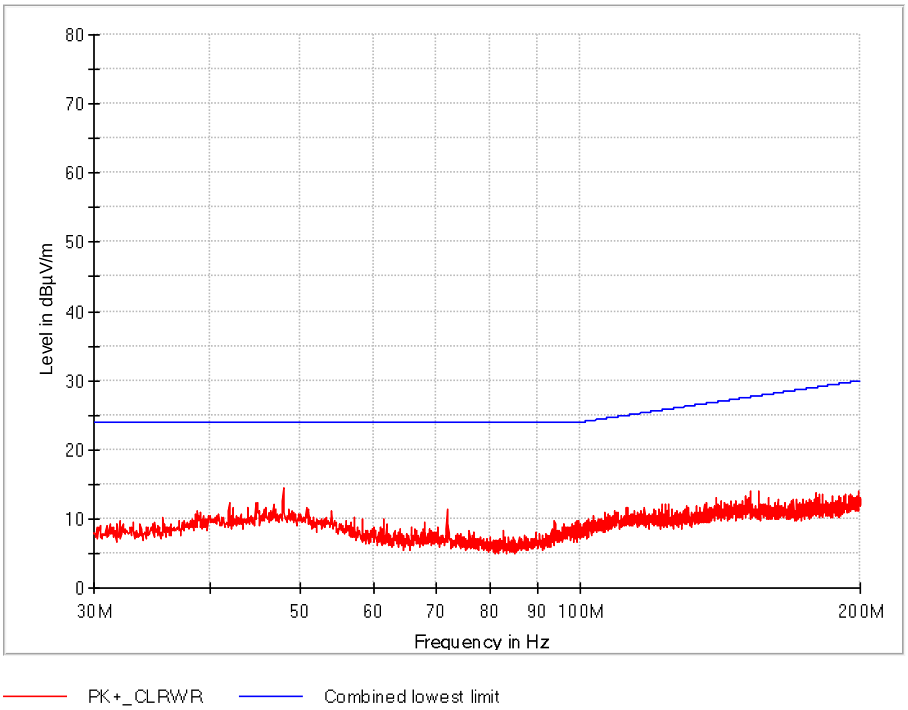
Plot 4.2.2 Test results regarding RE102, Radiated emissions, electric field. 2-30 MHz Ambient.



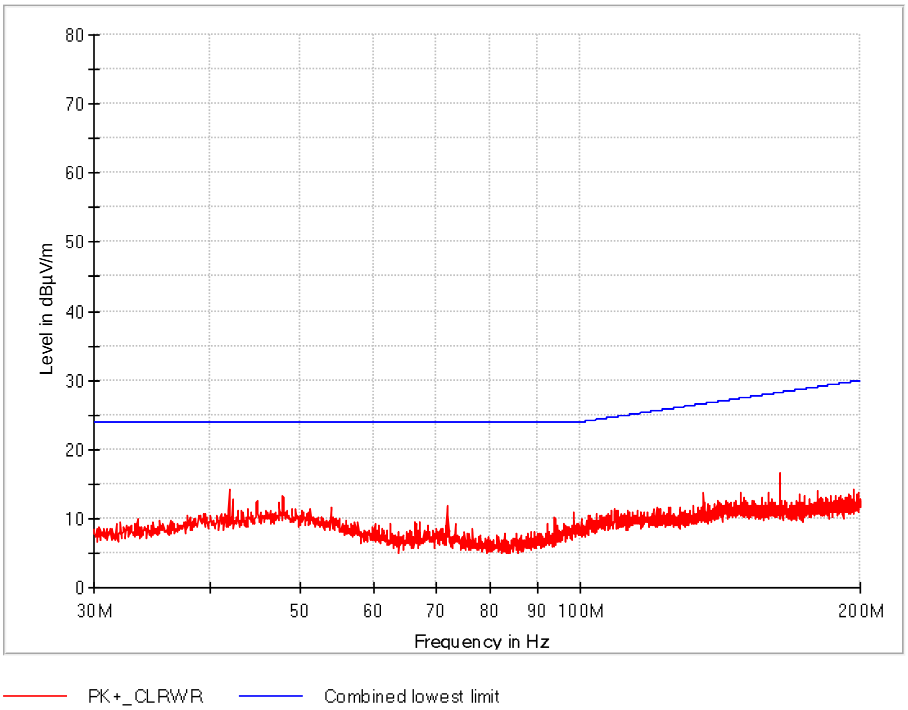
Plot 4.2.3 Test results regarding RE102, Radiated emissions, electric field. 2-30 MHz.



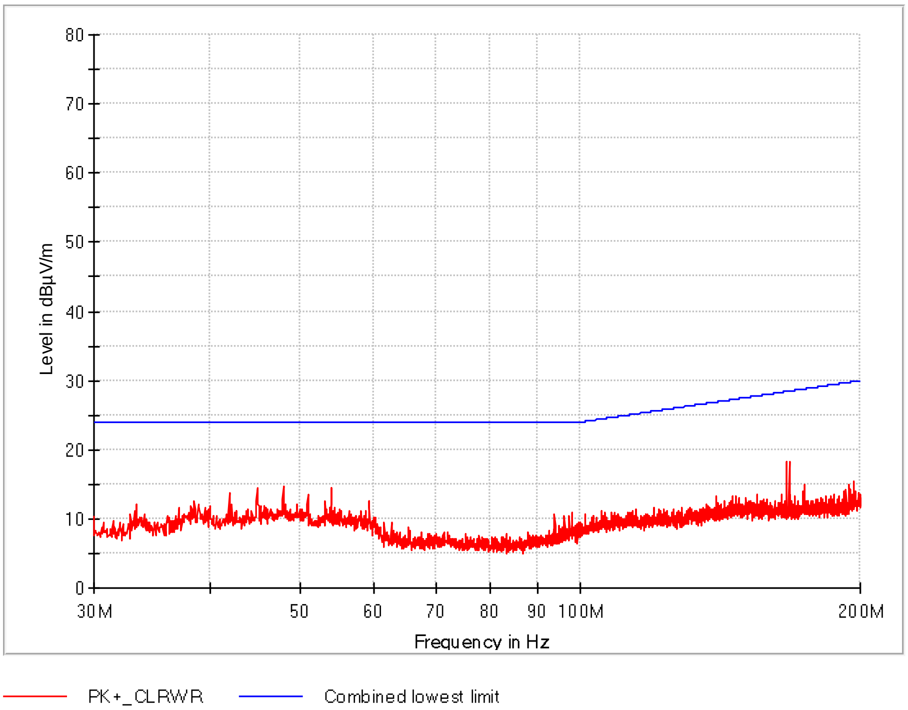
Plot 4.2.4 Test results regarding RE102, Radiated emissions, electric field. 30-200 MHz System check. 24 dBµV/m at 197 MHz.



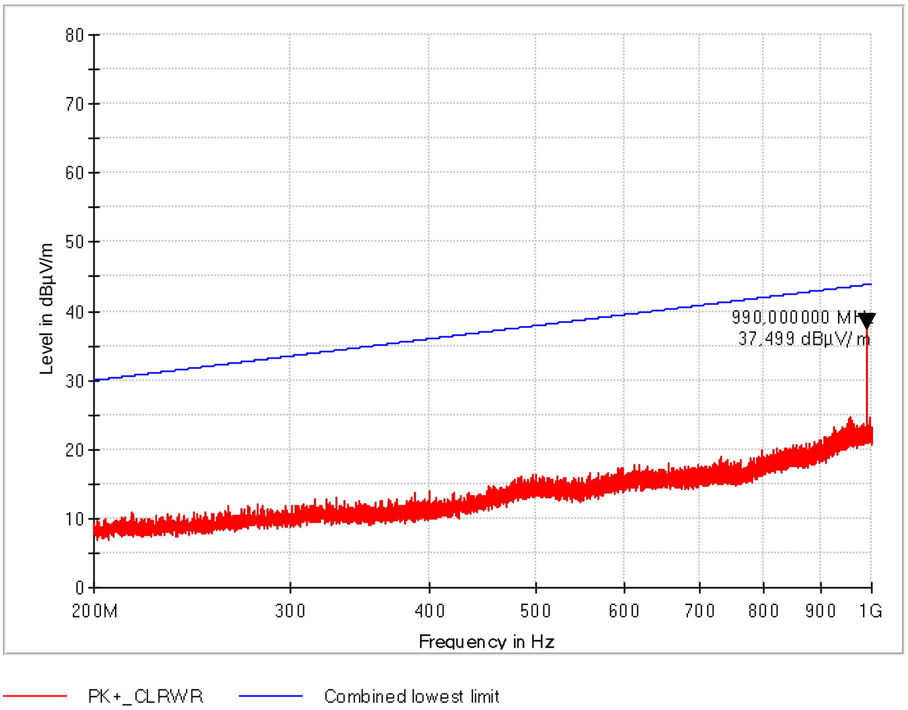
Plot 4.2.5 Test results regarding RE102, Radiated emissions, electric field.30-200 MHz Ambient.



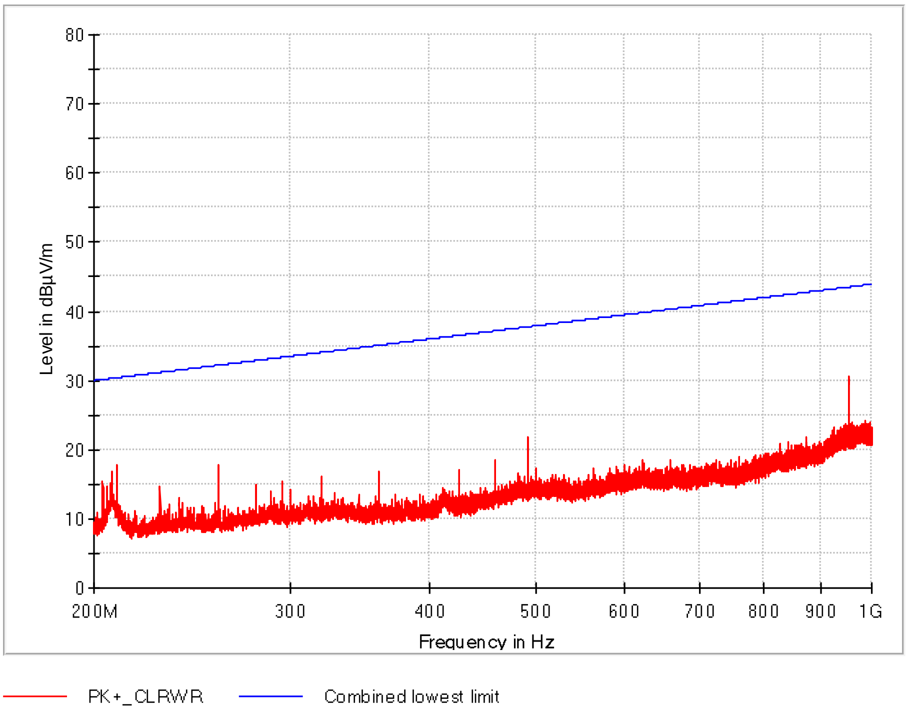
Plot 4.2.6 Test results regarding RE102, Radiated emissions, electric field. 30-200 MHz, Horizontal.



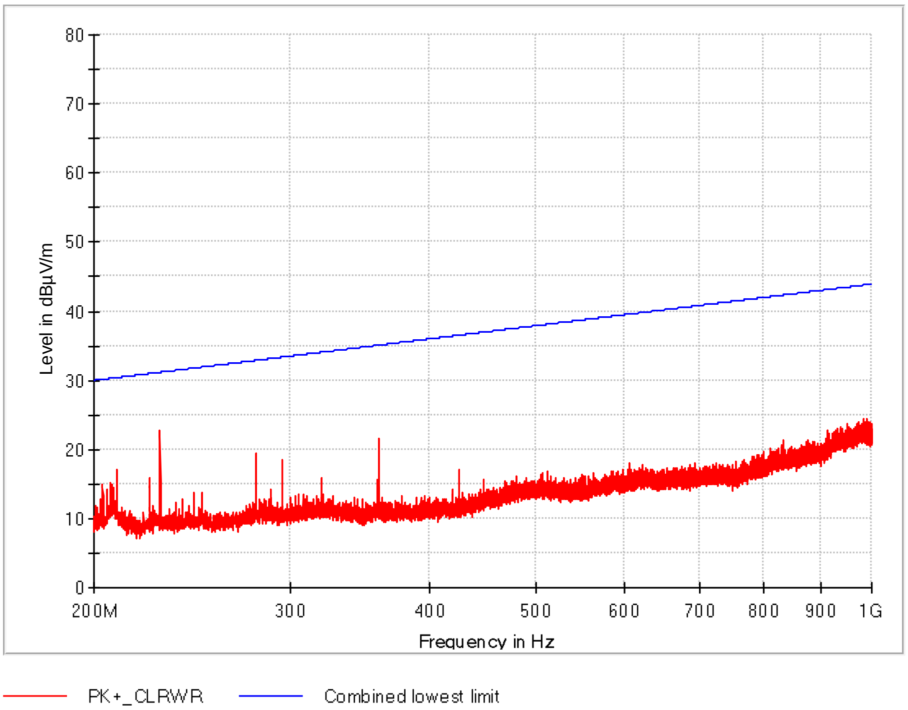
Plot 4.2.7 Test results regarding RE102, Radiated emissions, electric field.30-200 MHz Vertical.



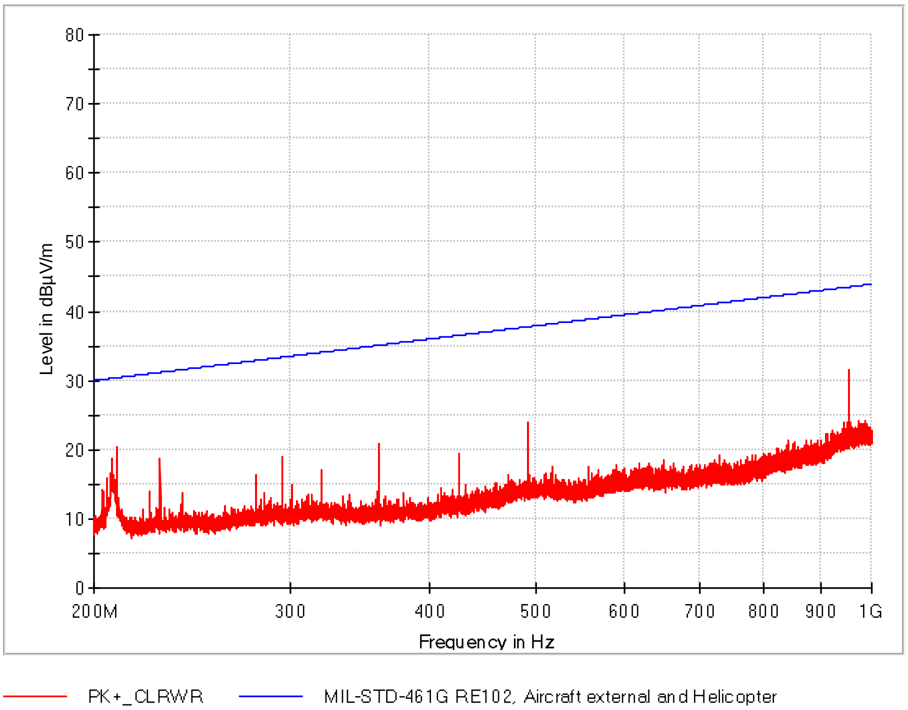
Plot 4.2.8 Test results regarding RE102, Radiated emissions, electric field. 200-1000 MHz System check. 35 dBµV/m at 990 MHz.



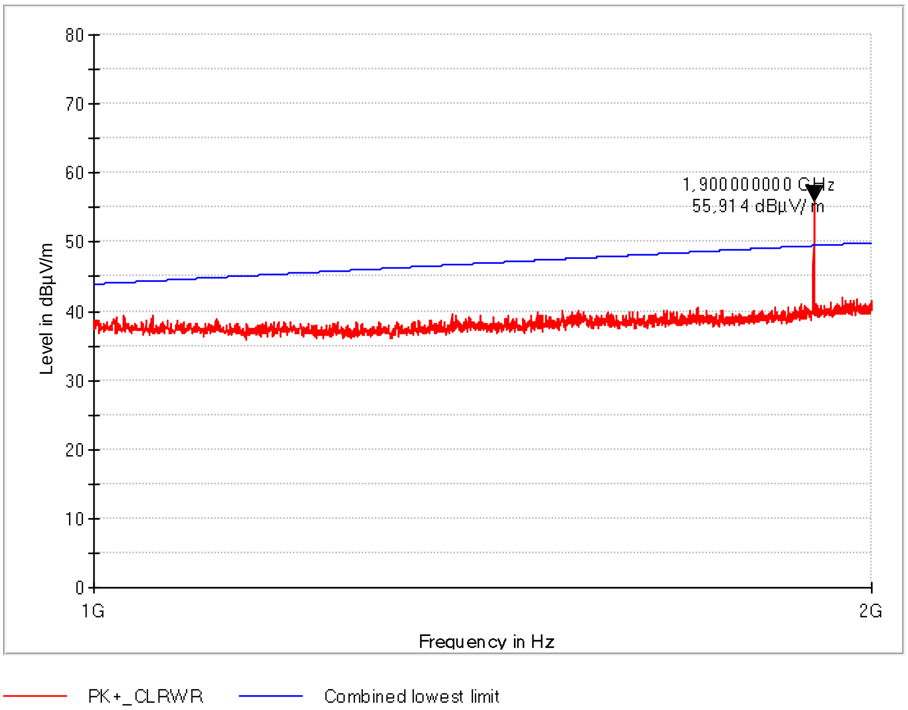
Plot 4.2.9 Test results regarding RE102, Radiated emissions, electric field.200-1000 MHz Ambient.



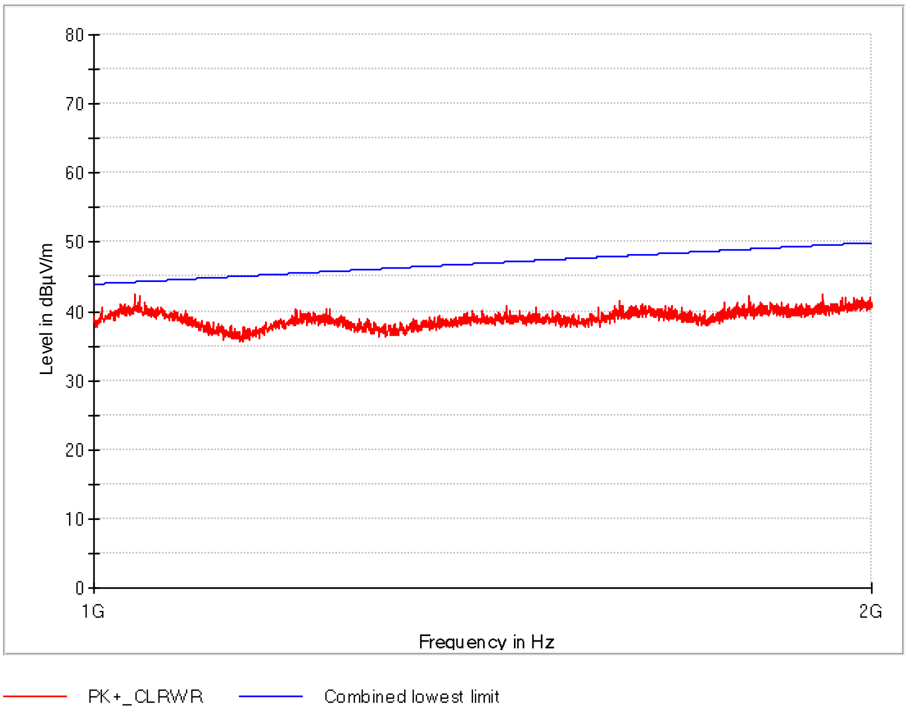
Plot 4.2.10 Test results regarding RE102, Radiated emissions, electric field. 200-1000 MHz, Horizontal.



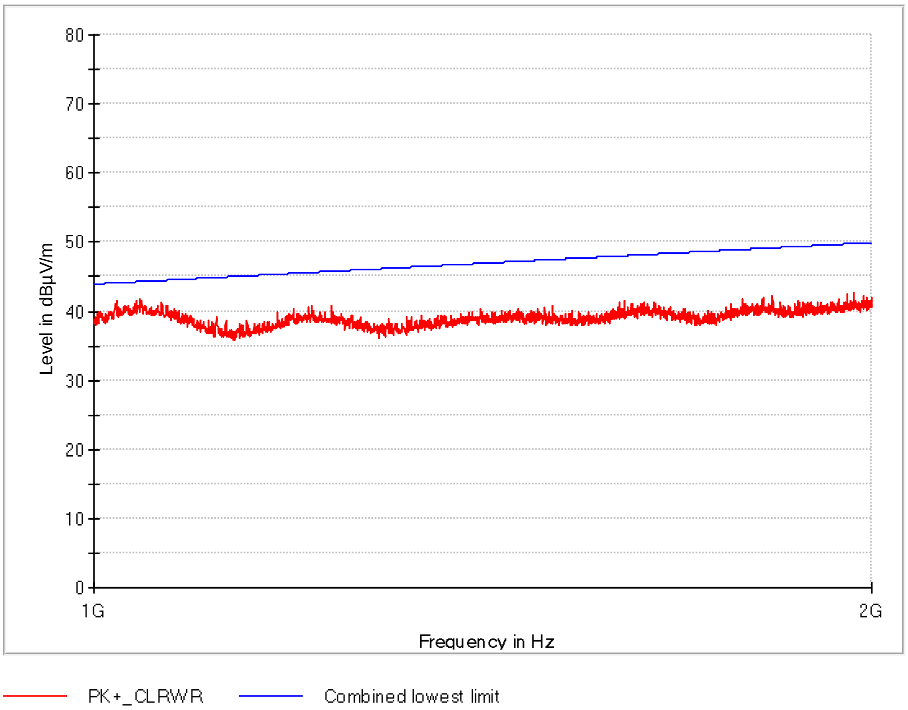
Plot 4.2.11 Test results regarding RE102, Radiated emissions, electric field.200-1000 MHz Vertical.



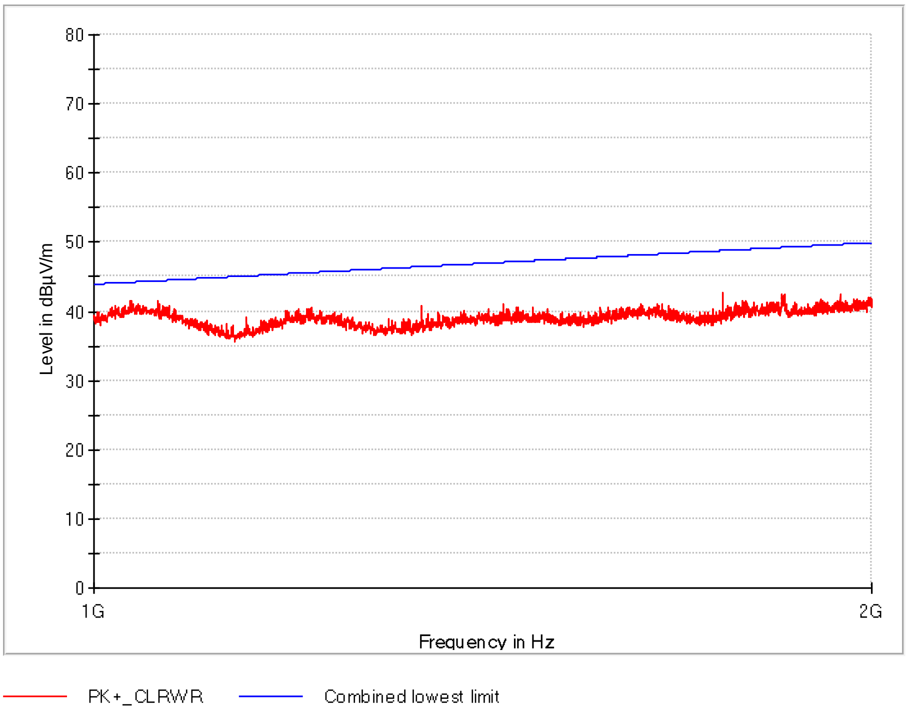
Plot 4.2.12 Test results regarding RE102, Radiated emissions, electric field. 1-2 GHz, System check 55 dBµV/m at 1.9 GHz.



Plot 4.2.13 Test results regarding RE102, Radiated emissions, electric field. 1-2 GHz, Ambient.



Plot 4.2.14 Test results regarding RE102, Radiated emissions, electric field. 1-2 GHz, Horizontal.



Plot 4.2.15 Test results regarding RE102, Radiated emissions, electric field. 1-2 GHz, Vertical.

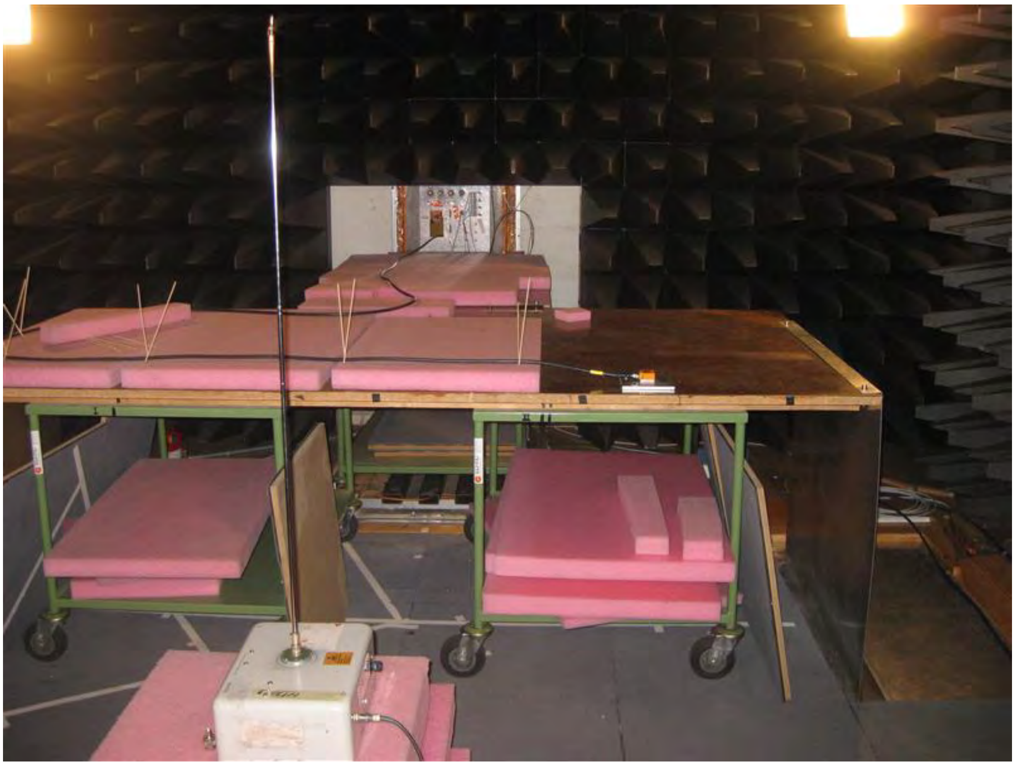


Photo 4.2.1 Test setup regarding RE102, Radiated emissions, electric field.

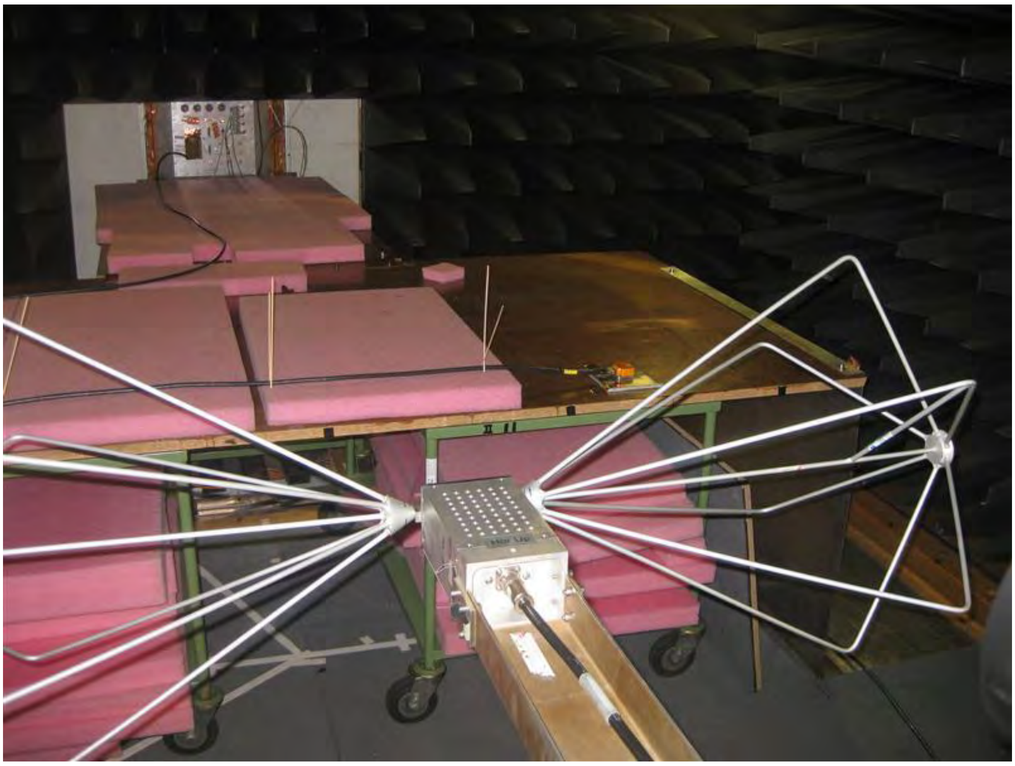


Photo 4.2.2 Test setup regarding RE102, Radiated emissions, electric field.

Photo 4.2.3 Test setup regarding RE102, Radiated emissions, electric field.

Photo 4.2.4 Test setup regarding RE102, Radiated emissions, electric field.

5. National registrations and accreditations

5.1 DANAK Accreditation

Organization: Danish Accreditation and Metrology Fund - DANAK, see www.danak.dk and www.ilac.org

Registration Number: 19

Area Number: C

DANAK is part of ILAC (International Laboratory Accreditation Cooperation) including its MRA (Mutual Recognition Arrangement). The MRA includes the Australian NATA and Canadian SCC.

5.2 FCC Registrations

Organization: Federal Communications Commission, USA

Registration Number: 913950

Facilities: EMC room 2 Hørsholm (EMC-2)
EMC room 3 Hørsholm (EMC-3)
EMC room 4 Hørsholm (EMC-4)
EMI room Hørsholm (EMC-5)

5.3 VCCI Registrations

Organization: Voluntary Control Council for Interference by Information Technology, Japan

Member Number: 910

Facilities:	EMC room 3 Hørsholm (EMC-3):	C-12532 and T-11548
	EMI room Hørsholm (EMC-5):	R-11180, C-10706 T-11550 and G-10470

5.4 IC Registrations

Organization: Industry Canada, Certification and Engineering Bureau

Registration Number: IC4187A-5

Facilities: EMI room Hørsholm (EMC-5)

6. List of instruments

No.	Description	Manufacturer	Type No.
29224	BROADBAND ROD ANTENNA	SINGER	95010-1
29275	LISN, MIL-STD-462/3, 50 µH	EC	10 kHz-50 MHz
29735	BULK CURRENT INJECTION PROBE, 10 kHz-400 MHz	FISCHER CUSTOM COMMUNICATIONS INC.	F-120-1
29753	BICONICAL ANTENNA, 20-300 MHz	EMCO	3109
29841	-40 dBc VOLTAGE SAMPLER, DC-100 MHz	DELTA EMC DEPT.	SAMPLER_VER_2
29875	RIDGED GUIDE HORN ANTENNA, 200 MHz - 2 GHz	EMCO	3106
49173	HF GENERATOR	Marconi	2024
49503	CABLE 0.5m BNC-BNC	SUHNER	RG223/U
49555	EMI Test Receiver, 20Hz-26GHz	ROHDE & SCHWARZ	ESU26
49558	RF POWER ATTENUATOR, 50 OHM, 6 dB, 100 W	JFW	50FH-006-100
49626	CABLE 1 m BNC-BNC	SUHNER	RG 223/U
49692	CABLE 5m BNC-BNC	SUHNER	RG 223/U
49697	CABLE 5m BNC-BNC	SUHNER	RG 223/U
49729	1-18 GHz. HORN ANTENNA.	ROHDE & SCHWARZ	4070.7000.02
49810	NRP-Z91 POWER SENSOR	ROHDE & SCHWARZ	1168.8004.02
49824	CABLE SF126EA SMA-SMA 7 m	HUBER & SUHNER	SF126EA/11SMA/11SMA/7000
49867	BROADBAND POWER AMPLIFIER, 10 kHz-250 MHz, 75 W	AMPLIFIER RESEARCH	75A250
49871	CABLE 5 M PC3.5 MALE-MALE SUCOFLEX 126	HUBER+SUHNER	SF126/11PC35/11PC35/5000MM
49872	CABLE 5 2 PC3.5 MALE-MALE SUCOFLEX 126	HUBER+SUHNER	SF126/11PC35/11PC35/2000MM