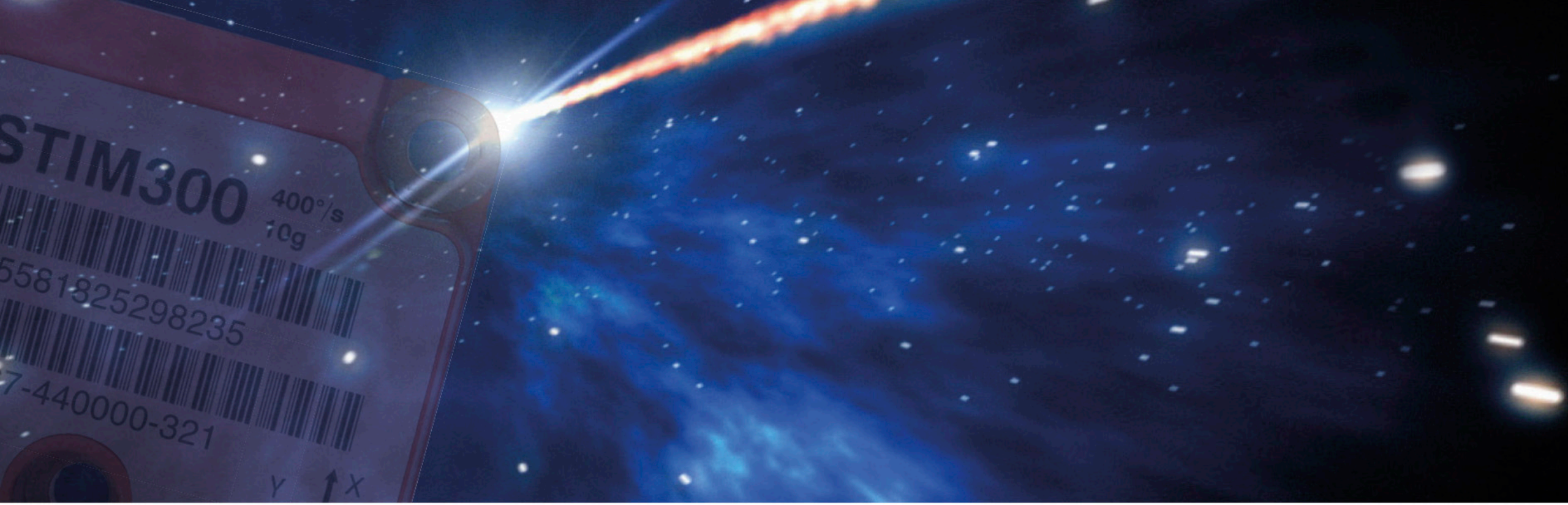


COTS for Space - Radiation Characterization of Gyro and IMUs for LEO Operations

Hans Richard Petersen

Sensonor

MEMS Fabrication

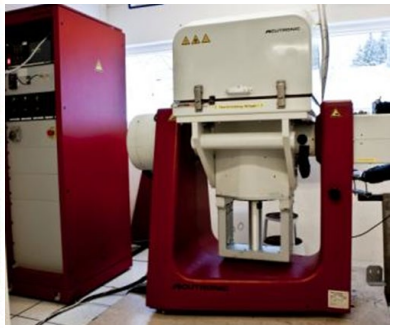
Frontend Wafer Fab

- State of the art 150mm MEMS line
- Line upgraded 2008 & 2016
- Production / clean room area: 2600m^2

Capacity

- 700 triple stack wafer starts per week
- 133,000 gyros annually

Gyro and IMU Production



Packaging and Test

- Fully automated flexible assembly line
- Development and qualification lab
- Production / clean room area: 4000m^2

Capacity

- 10,000 STIM202/210 Gyro Modules per year
- 5,000 STIM300 IMUs per year

Sensonor – space heritage

- Aerospace Corp - AeroCube-4 launched the STIM210 gyro into space in 2012
- Several papers was published on this
- NASA evaluated the part and used it for the RAVEN project at ISS
- Several others followed
- All utilized a standard component

Gyro and IMU for characterization

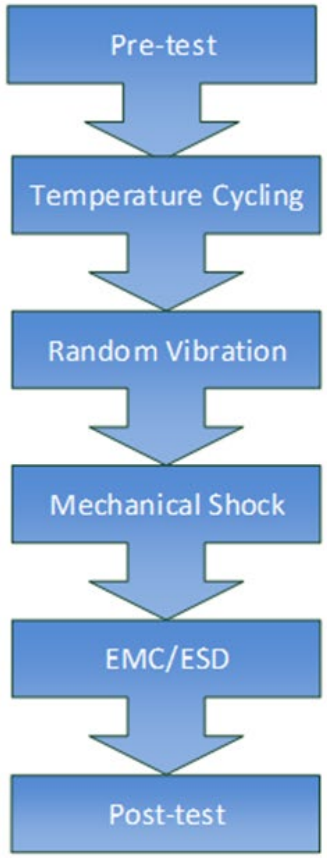
STIM210 Gyro Module
STIM210 is a tactical grade (Bias Stability 0.3°/h, ARW 0.15°/√h) gyro module. Electronic axis alignment is standard.

STIM300 IMU module
STIM300 is a tactical grade IMU. It contains 3 gyros, 3 accelerometers and 3 inclinometers. The IMU is factory calibrated over temperature and for Scale Factor errors.

Test overview

- **Technology Acceptance test** (4+2) is a set of tests to verify that the STIM technology is ready for Space. These tests do not contain irradiation tests, but other types of environmental tests like vibrations, temperatures and EMC.
- **Single-Event Effect test** (10) is a set of tests to characterize the occurrence of single-events in the STIM products when bombarded with protons.
- **Total Ion Dose test** (24) is a set of tests to characterize the effect of irradiation of the STIM products. Half of the parts where powered during the irradiation and half were unpowered.

Technology Acceptance test - plan



Characterization over temperature, rate and g (g for STIM300 only)
STIM210: 2pcs, STIM300: 2pcs

Reference: ECSS-E-10-03a15Feb2002
Temperatures: -40°C /+85°C, Cycles: 8, Dwell-time: 2 hours, Gradient: <20°C/min
Unpowered
STIM210: 2pcs, STIM300: 2pcs

Reference: ECSS-E-10-03a15Feb2002, table 20
Total grms: 6.06, Spektrum:
Powered
STIM210: 2pcs, STIM300: 2pcs

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

Reference: MIL STD 883G method 2002.4
Amplitude: 1500g, Pulse-width: 0.5ms, half sinus, Shocks: 5 in each X-Y-Z direction
Powered
STIM210: 2pcs, STIM300: 2pcs

Reference: MIL-STD 461F, according to table V; "Requirement matrix", space:
Unpowered
STIM210: 1pcs, STIM300: 1pcs

Characterization over temperature, rate and
g (g for STIM300 only)
STIM210: 2pcs, STIM300: 2pcs

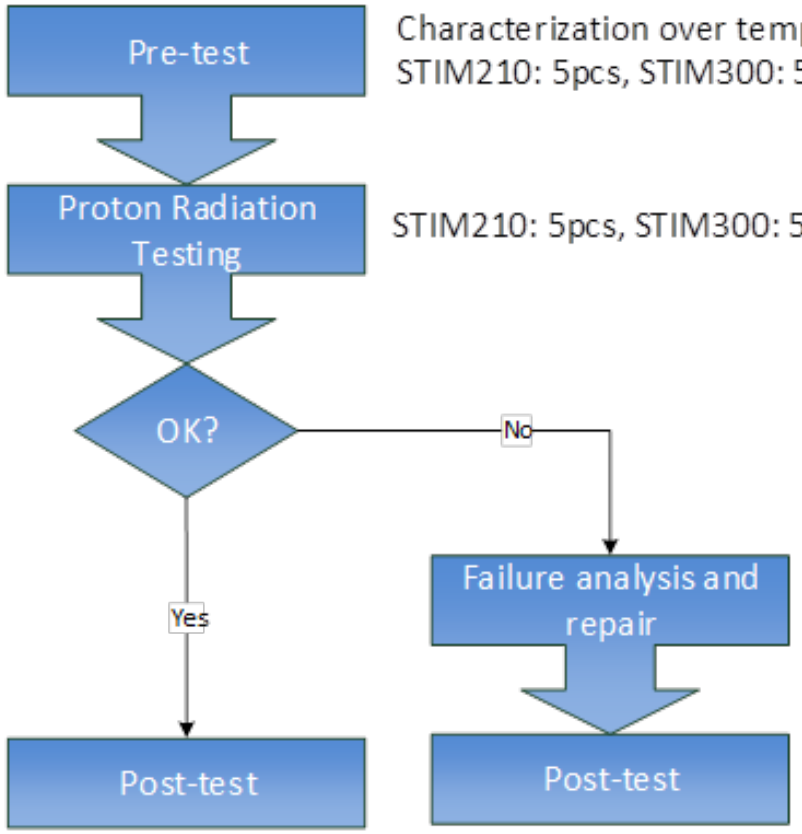
Technology Acceptance test - results

- All parts passed the post-tests
- STIM210 and STIM300 have a general robustness to function in Space

Summary of Technology Acceptance test

Product	Gyro	Accelerometer	Inclinometer
STIM210	Pass	-	-
STIM300	Pass	Pass	Pass

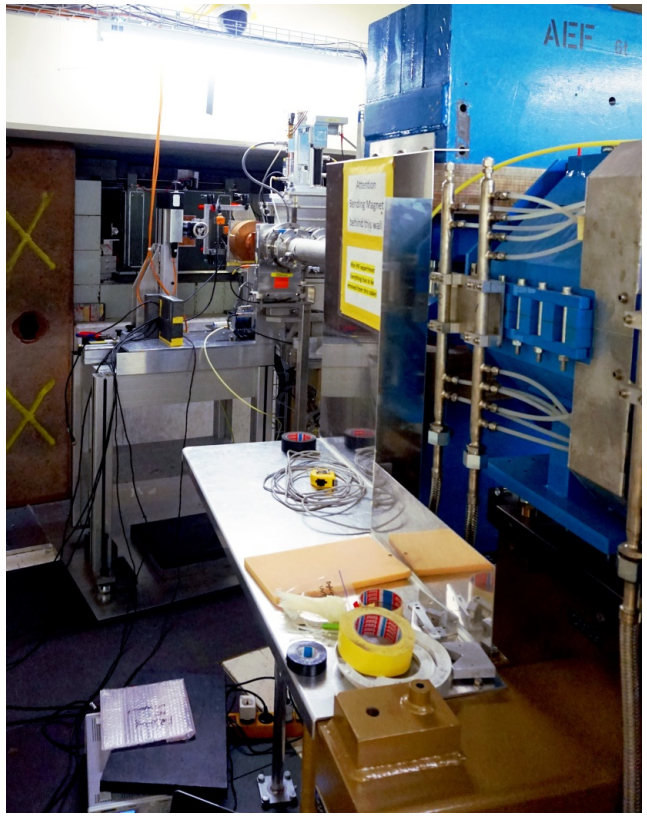
Single-Event Effect test – SEE plan



Characterization over temperature, rate and g (g for STIM300only)
STIM210: 5pcs, STIM300: 5pcs

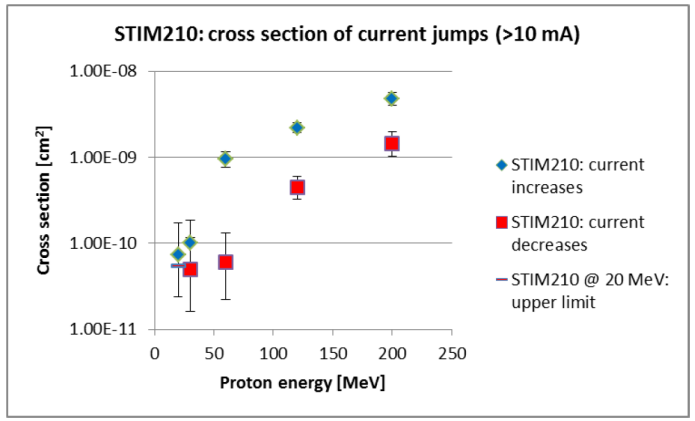
STIM210: 5pcs, STIM300: 5pcs

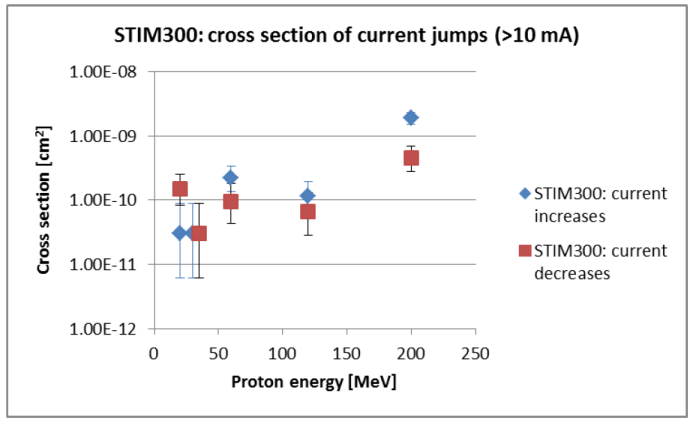
Energy level [MeV]	STIM210 #1	#2	#3	#4	#5	STIM300 #1	#2	#3	#4	#5
200			X	X		X				
120	X	X					X			
60		X						X		
30			X						X	
20					X					X
Fluence	$>=10^{11}$ p/cm^2									

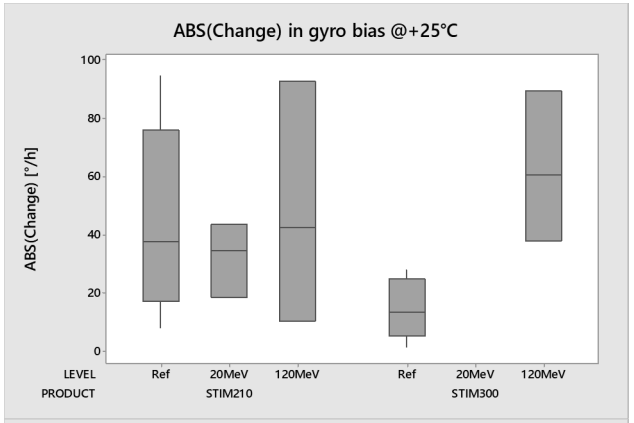


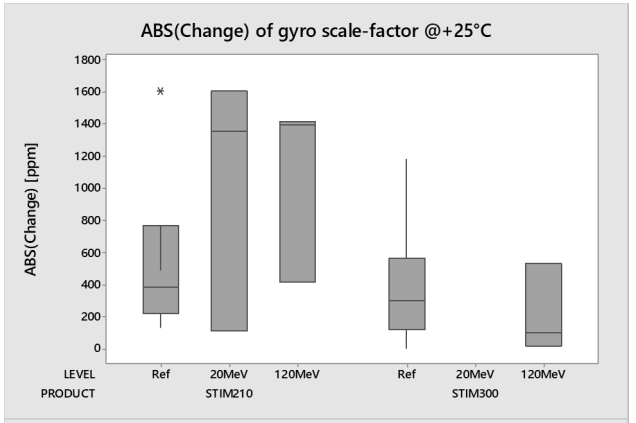
Characterization over temperature, rate and g (g for STIM300 only)
STIM210: 5pcs, STIM300: 5pcs

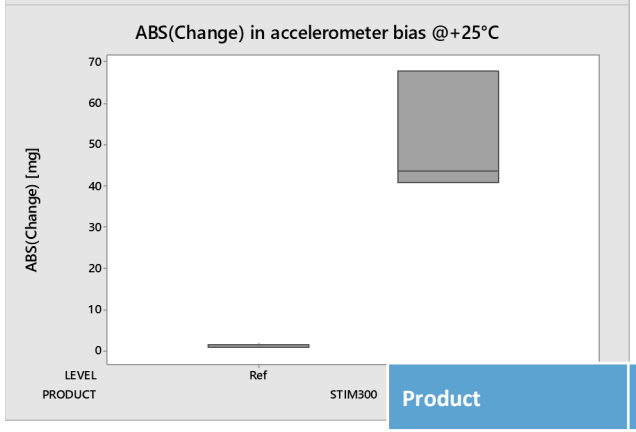
Single-Event Effect test - results

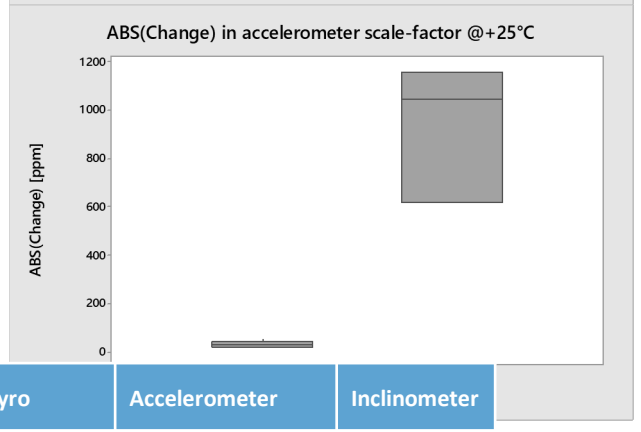






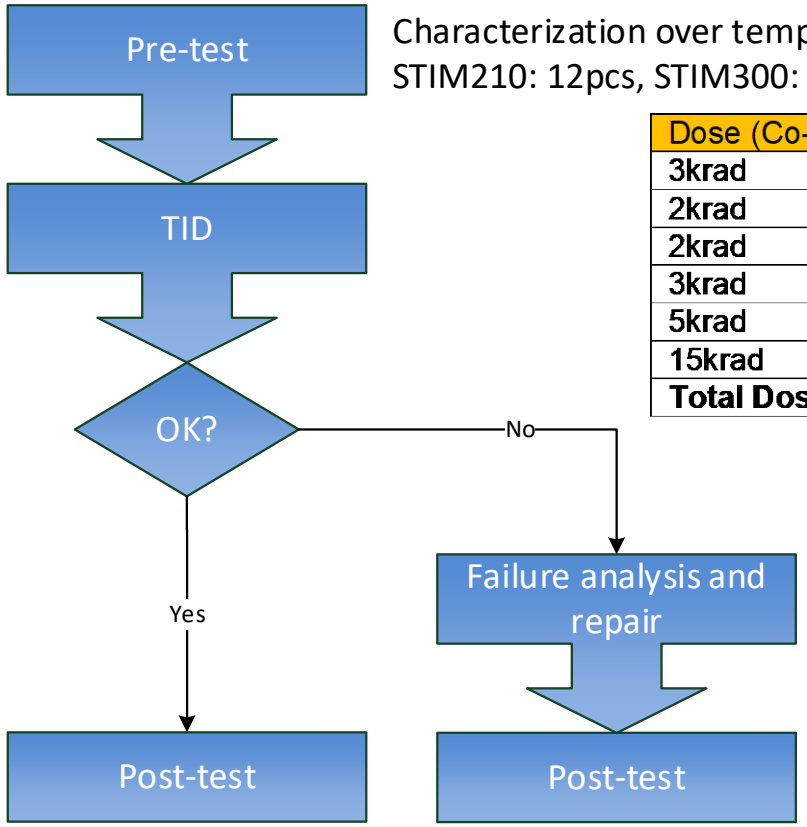






Product	Gyro	Accelerometer	Inclinometer
STIM210	Pass	-	-
STIM300	Pass	Bias+SF affected	Bias+SF affected

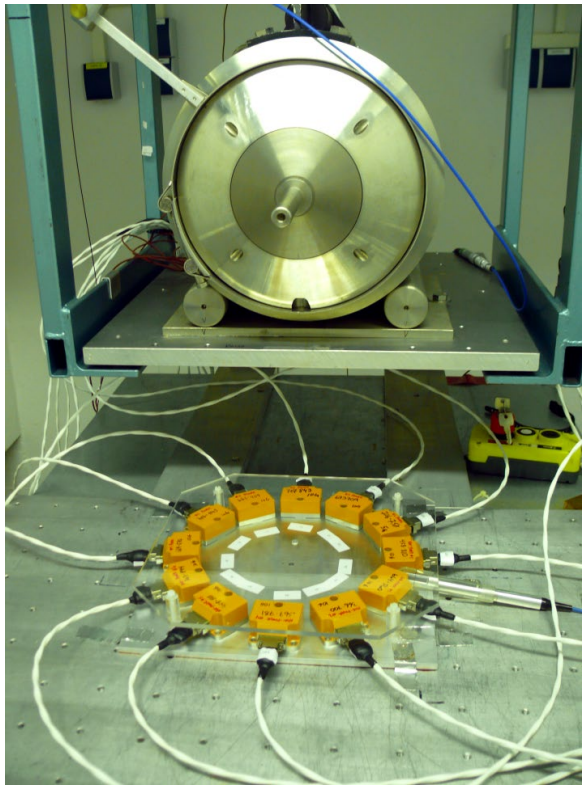
Total Ion Dose test - plan



Characterization over temperature, rate and g (g for STIM300 only)
STIM210: 12pcs, STIM300: 12pcs

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**

Number of pieces in table above is for each IMU:
STIM210: 12pcs, STIM300: 12pcs



Characterization over temperature, rate and g (g for STIM300 only)
STIM210: 12pcs, STIM300: 12pcs

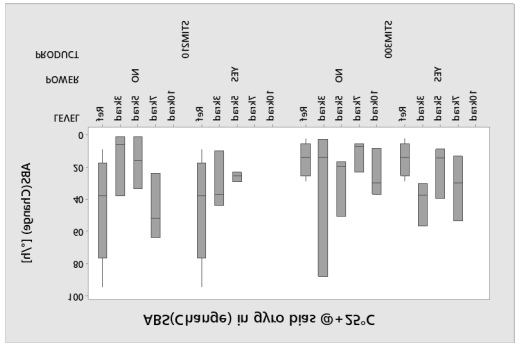
Total Ion Dose test - results

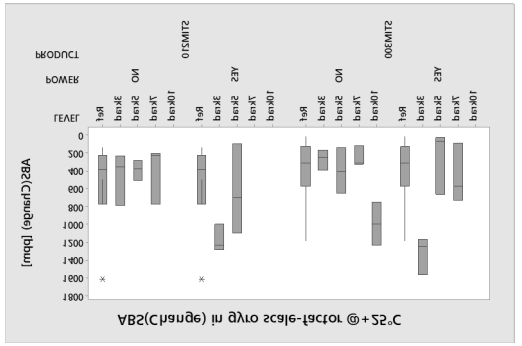
#	Dose step	STIM210											
		Powered						Unpowered					
		#1	#2	#3	#4	#5	#6	#1	#2	#3	#4	#5	#6
0	Pre-irradiation												
1	0 -> 3 krad												
2	3 -> 5 krad												
3	5 -> 7 krad												
4	7 -> 10 krad												
5	10 -> 15 krad												
6	15 -> 30 krad												

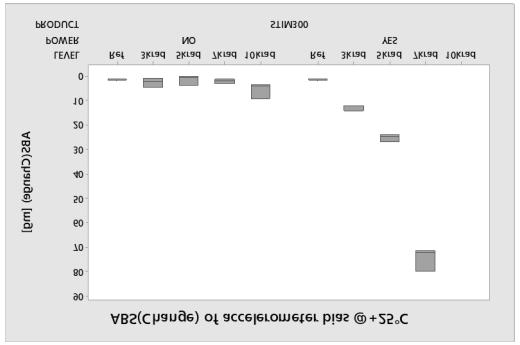
Not included at dose step
Passed at post-irradiation tes
Failed at post-irradiation test
No communication at post-irradiation test

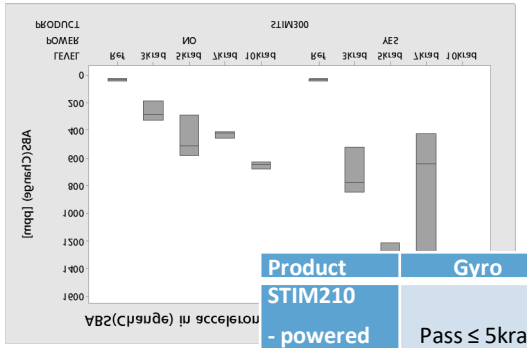
#	Dose step	STIM300											
		Powered						Unpowered					
		#1	#2	#3	#4	#5	#6	#1	#2	#3	#4	#5	#6
0	Pre-irradiation												
1	0 -> 3 krad												
2	3 -> 5 krad												
3	5 -> 7 krad												
4	7 -> 10 krad												
5	10 -> 15 krad												
6	15 -> 30 krad												

Not included at dose step
Passed at post-irradiation tes
Failed at post-irradiation test
No communication at post-irradiation test



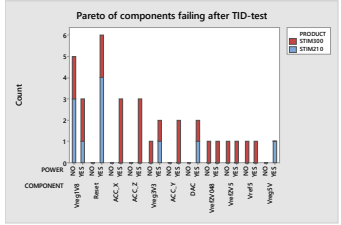


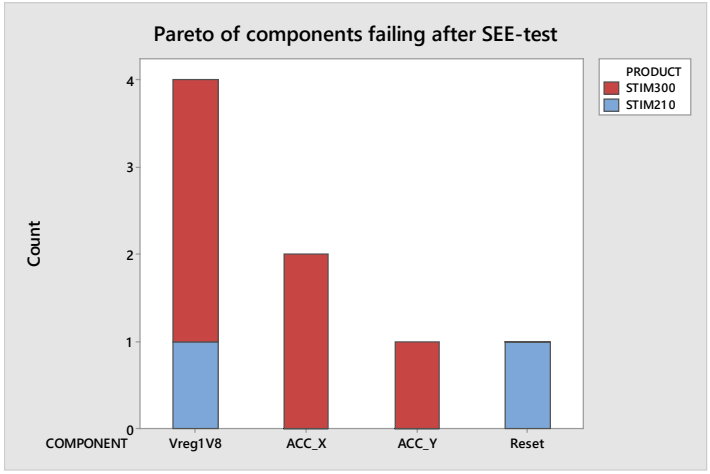


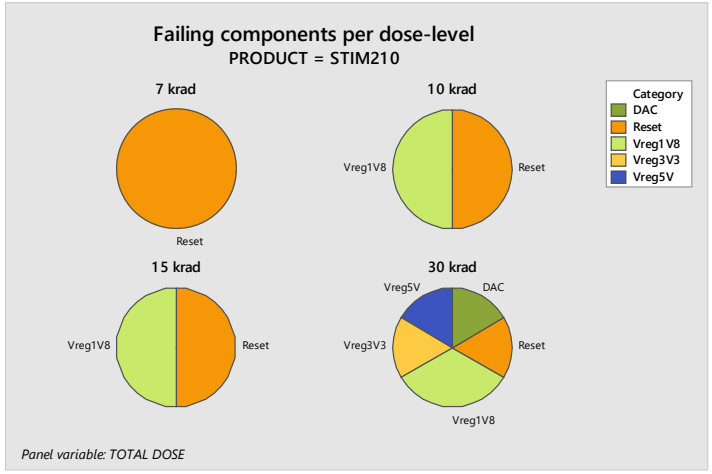


Product	Gyro	Accelerometer	Inclinometer
STIM210			
- powered	Pass ≤ 5krad	-	-
- unpowered	Pass ≤ 7krad	-	-
STIM300			
- powered	Pass ≤ 5krad	Bias+SF affected	Bias+SF affected
- unpowered	Pass ≤ 7krad	Bias+SF affected	Bias+SF affected

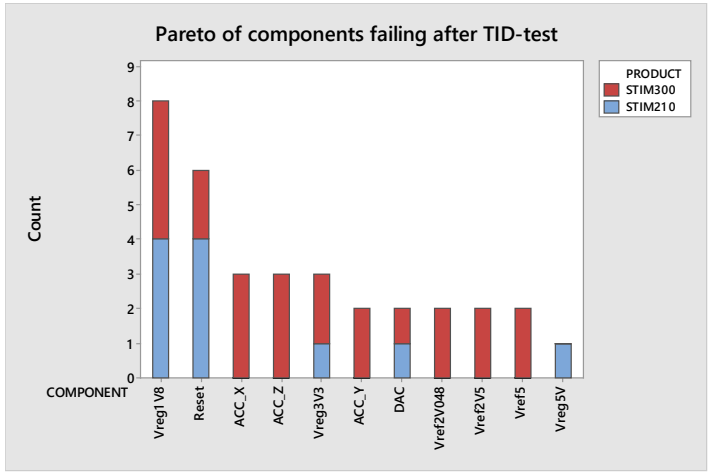
Failure analysis

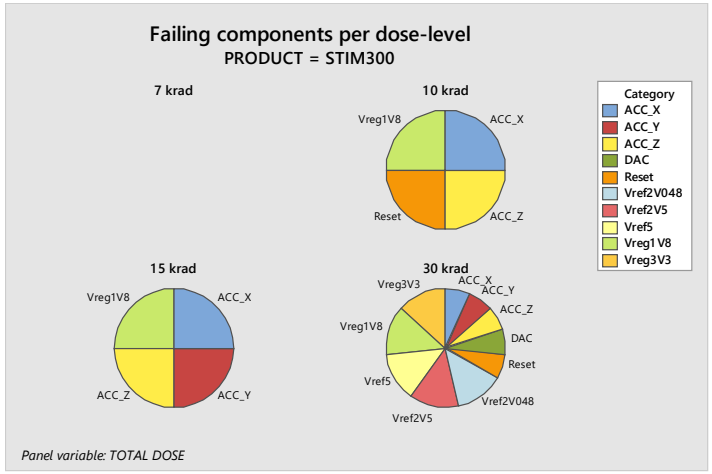






Component	Manufacturer part number	Manufacturer
Reset	TPS3808G01DBVTG4	Texas Instruments
Vreg1V8	LT1763CDE-1.8#PBF	Linear Technology
ACC (X,Y,Z)	MS9010.A	Colibrys
DAC	AD5308ARUZ	Analog Devices
Vreg3V3	TPS62290DRVTG4	Texas Instruments
VReg5V	LT1763CDE-5#PBF	Linear Technology
VRef2V048	ADR440ARMZ	Analog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





Conclusions

- Both STIM210 and STIM300 passed the Technology Acceptance
- Both products survive TID radiation levels up to 5krad when powered and up to 7krad when unpowered.
  - This radiation level is considered within reach for applications in Low Earth Orbit.
  - The performance of the gyros is maintained at radiation levels up to 5krad. However, the performance of the accelerometers and inclinometers in STIM300 is degraded when exposed to radiation and their use in Space should be carefully evaluated.
- The cross section related to single-events has been established for STIM210 and STIM300.
  - In the simulated case of a 10 year mission in helio-synchronous orbit at 800 km with 11.1mm aluminum shielding, several 10s of events must be expected.
- For the parts surviving the Single-Event Effect test, the gyro performance is maintained, while the accelerometers and inclinometers are degraded after proton irradiation.
- Failure analysis of the failing parts revealed the 1.8V regulator, the reset circuit and the accelerometers (STIM300 only) to be the least robust components with respect to radiation.

Questions, or to receive the complete test report
HRP@sensonor.no