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SEE test report summary

SCOC3 DC1034
ATMEL ATC18RHA

Spacecraft Controller On a Chip

	Name and function	Date	Signature
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1 INTRODUCTION

This document is the SCOC3 Radiation Test Report Summary. It summarizes the results of the heavy ions irradiations performed on the SCOC3 ASIC on 5-7 September 2012 at RADEF facility (Finland).

2 APPLICABLE DOCUMENTS

	Document	Reference
AD1	Single event effects test method and guidelines	ESCC basic specification N°25100 Iss 1, oct 2002
AD2	Single event effects test method and guidelines	ESA/SCC basic specification N°25100 Iss 1, oct 95.
AD3	Generic radiation hardness assurance requirements for space program	ADS-E-0631 Iss 2 Rev 00.
AD4	SCOC3 Radiation Test Plan, issue 0 rev 1, 27.8.2012	R&D.SCOC3.PL.01494.E.ASTR

3 REFERENCE DOCUMENTS

	Document	Reference
RD1	SCOC3 ASIC Data Sheet, Astrium	Astrium, R&D.SCOC3.NT.00980.V.ASTR
RD2	ASIC SCOC3 User's manual, Astrium	Astrium, R&D.SCOC3.NT.00660.V.ASTR
RD3	ATMEL ATC18RHA rad-hard CMOS 0.18µm cell-based ASIC family Radiation Test Report – Total Dose (TID) and Single Event Effects (SEE)	ATMEL, mtr050914, 14/09/2005
RD4	ATC18RHA Rad-Hard 0.18µm CMOS cell-based ASIC family for space use – Single Event Transients test report	ATMEL, ADF-MK-R0870-COS, version 1.0, 19/11/2007
RD5	ATC18RHA Rad-Hard 0.18µm CMOS cell-based ASIC family for space use – Protons Single Event Effects test report	ATMEL, ADF-MK-R0772-CUP, version 1.1, 20/09/2006
RD6	SCOC3 Radiation Assurance Report	Astrium, R&D.SCOC3.RP.01080.V.ASTR
RD7	RADEF website	https://www.jyu.fi/fysiikka/en/research/accelerator/radef
RD8	SRIM website	http://www.srim.org/#SRIM

4 ACRONYMS

AD	Applicable Document
ASIC	Application Specific Integrated Circuit
ATS	Acceptance Test Software
DFF	D-Type Flip Flop
DSU	Debug Support Unit
DUT	Device Under Test
EDAC	Error Detection And Correction
EEPROM	Electrically Erasable Programmable Read Only Memory
HW	HardWare
IEEE	Institute of Electrical and Electronics Engineers
IO	Input/Output
IP	Intellectual Property
MBU	Multiple Bit Upset
PDF	Portable Document Format
PROM	Programmable Read Only Memory
RAM	Random Access Memory
RD	Reference Document
RMAP	Remote Memory Access Protocol
ROM	Read Only Memory
SEE	Single Event Effect
SCoC	Spacecraft Controller on a Chip
SCOC3	Spacecraft Controller on a Chip 3
SDRAM	Synchronous Dynamic Random Access Memory
SEL	Single Event Latch-up
SEP	Single Event Phenomena
SET	Single Event Transient
SEU	Single Event Upset
SI	System International
SOC	System-On-a-Chip
SPW	SpaceWire
SRAM	Static Random Access Memory
SW	SoftWare
TBC	To Be Confirmed
TBD	To Be Defined
TC	TeleCommand

5 PART DETAILS

The device tested is the SCOC3 ASIC. It is fabricated in the ATMEL ATC18RHA rad-hard CMOS 0.18µm wafer technology and is packaged in a MCGA 472 pins ceramic package. Two SCOC3 parts were procured for this test.

6 TEST DESCRIPTION

6.1 HEAVY ION IRRADIATION FACILITY

The selected facility has been RADEF located at Jyvaskyla (Finland).

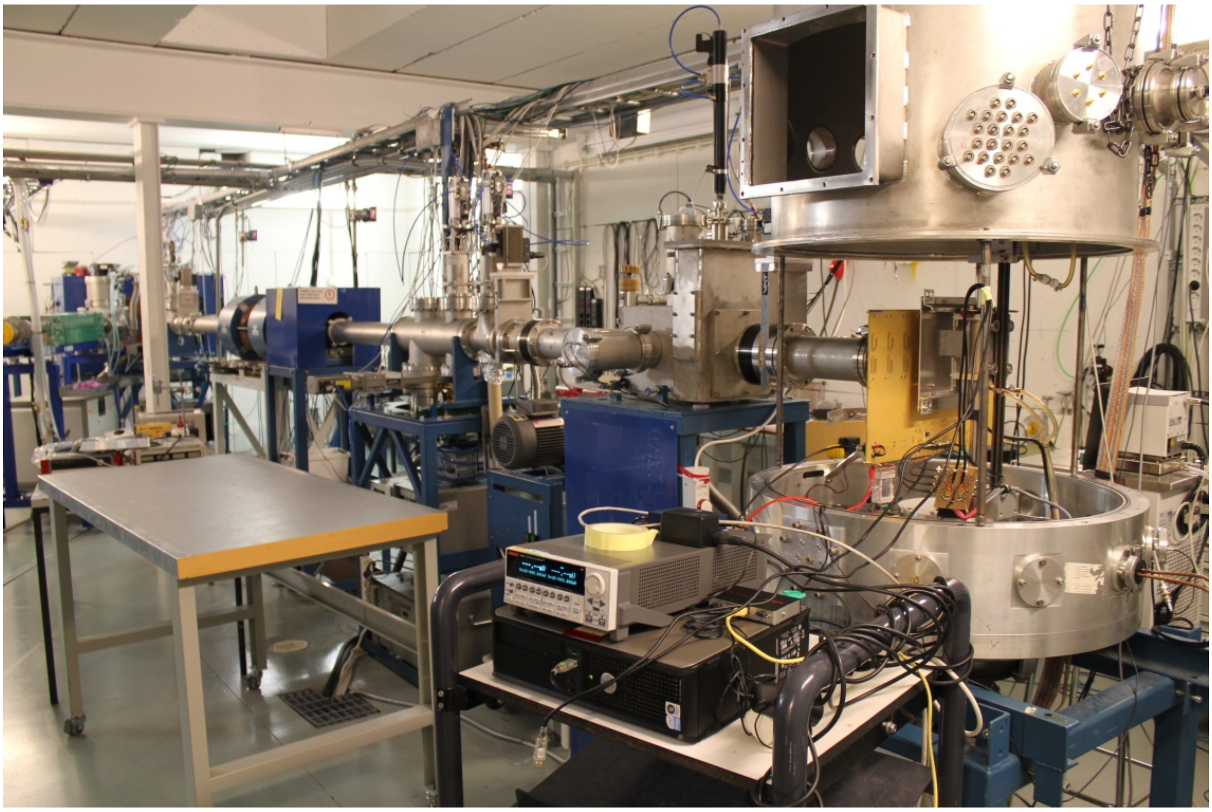

Figure 1: the irradiation chamber

The table below summarizes the experimental values for LET in silicon target and also corresponding estimates from SRIM-2003.26 code for comparison. The LET values for these ions with different energies can be calculated using the semi-empirical estimations based on the classical Bohr theory for electronic stopping.

Ion	Energy [MeV]	LET MEAS @surface [MeV/mg/cm²]	LET MEAS @Bragg peak [MeV/mg/cm²]	LET SRIM @surface [MeV/mg/cm²]	RANGE SRIM [microns]	LET SRIM @Bragg peak [MeV/mg/cm²]	Range in air [µm Si]	LET in air @surface [MeV/mg/cm²]
$^{15}N^{4+}$	139	1.87	5.92(@191 µm)	1.83	202.0	5.9(@198 µm)	178.0	2.0
$^{20}Ne^{6+}$	186	3.68	9.41 (@138 µm)	3.63	146.0	9.0 (@139 µm)	122.0	4.0
$^{30}Si^{8+}$	278	6.74	13.7 (@114 µm)	6.4	130.0	14.0 (@120 µm)	106.0	7.0
$^{40}Ar^{12+}$	372	10.08	18.9 (@100 µm)	10.2	118.0	19.6 (@105 µm)	94.0	11.0
$^{56}Fe^{15+}$	523	18.84	29.7 (@75 µm)	18.5	97.0	29.3 (@77µm)	73.0	20.5
$^{82}Kr^{22+}$	768	30.44	41.7 (@68 µm)	32.2	91.0	41.0 (@69 µm)	70.0	35.0
$^{131}Xe^{35+}$	1217	54.95	67.9 (@57 µm)	60.0*	89*	69.2 (@48 µm)	65.0	65.0

*Estimated values for 1.22GeV Xenon in Silicon

Table 1: 9.3 MeV/amu cocktails (M/Q≈3.7, ‡M/Q≈3.3).

In free air, the ion characteristics are slightly different from Figure 1, range has to be reduced by 24µm and LET increased by around 10%. The following figure shows the LET vs depth in silicon, the 24µm line represent the die surface when operated in free air conditions. The remaining range is at least more than 60µm for all ions, and is sufficient to assess SEE behaviour of the part.

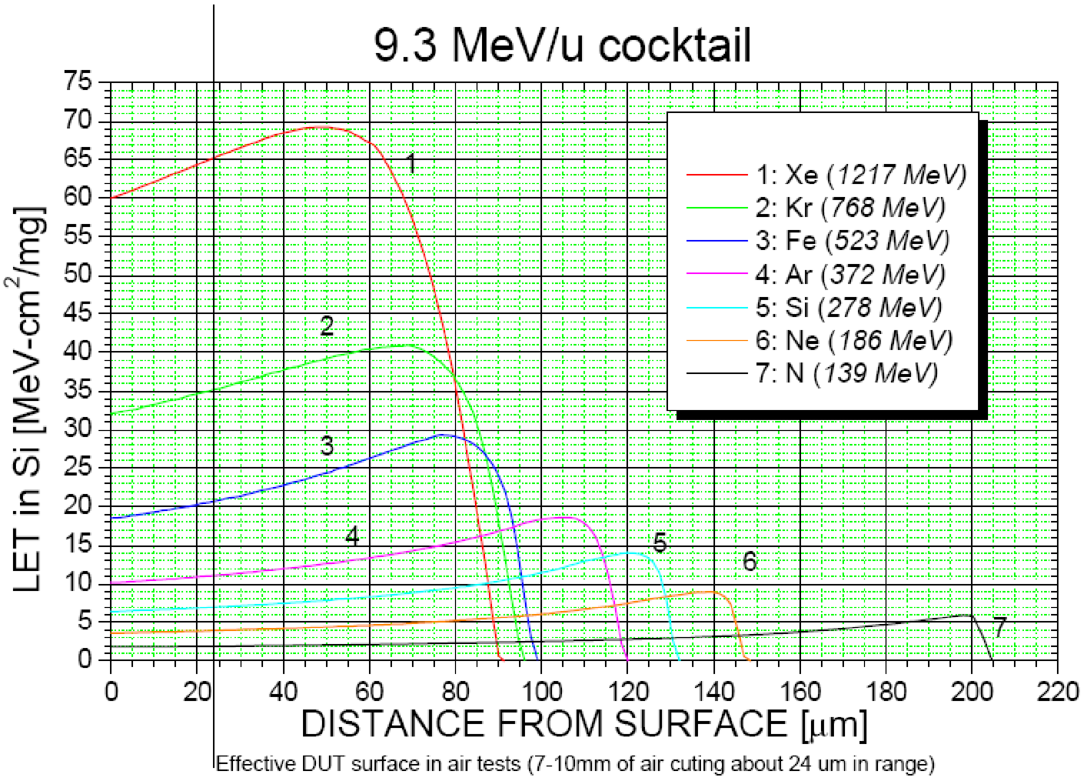

Figure 2: LET vs depth in silicon for 9.3MeV/u cocktail

6.2 TEST SET UP DESCRIPTION

The unit tester is based on a couple of boards and two remote computers:

- The main board is dedicated to SCOC3 testing. The main advantage of this board is the limited number of peripheral components and also a very simplified connection interface. The test board implements a soldered SCOC3.
- It is connected to a sbRIO board (from National Instruments) which includes an FPGA and a real-time processor. All software including FPGA coding is managed under Labview.
- All collected data by SbRIO board are sent to the Labview remote control computer by Ethernet. Additionally, test setup includes supply monitoring with latchup detection and protection. Moreover, two temperature sensors are sticked onto the SCOC3 package for temperature information.
- A second computer, the DSUCmd remote control computer, enables to compile the tests, to load them and to collect the messages sent by SCOC3 on UART1.

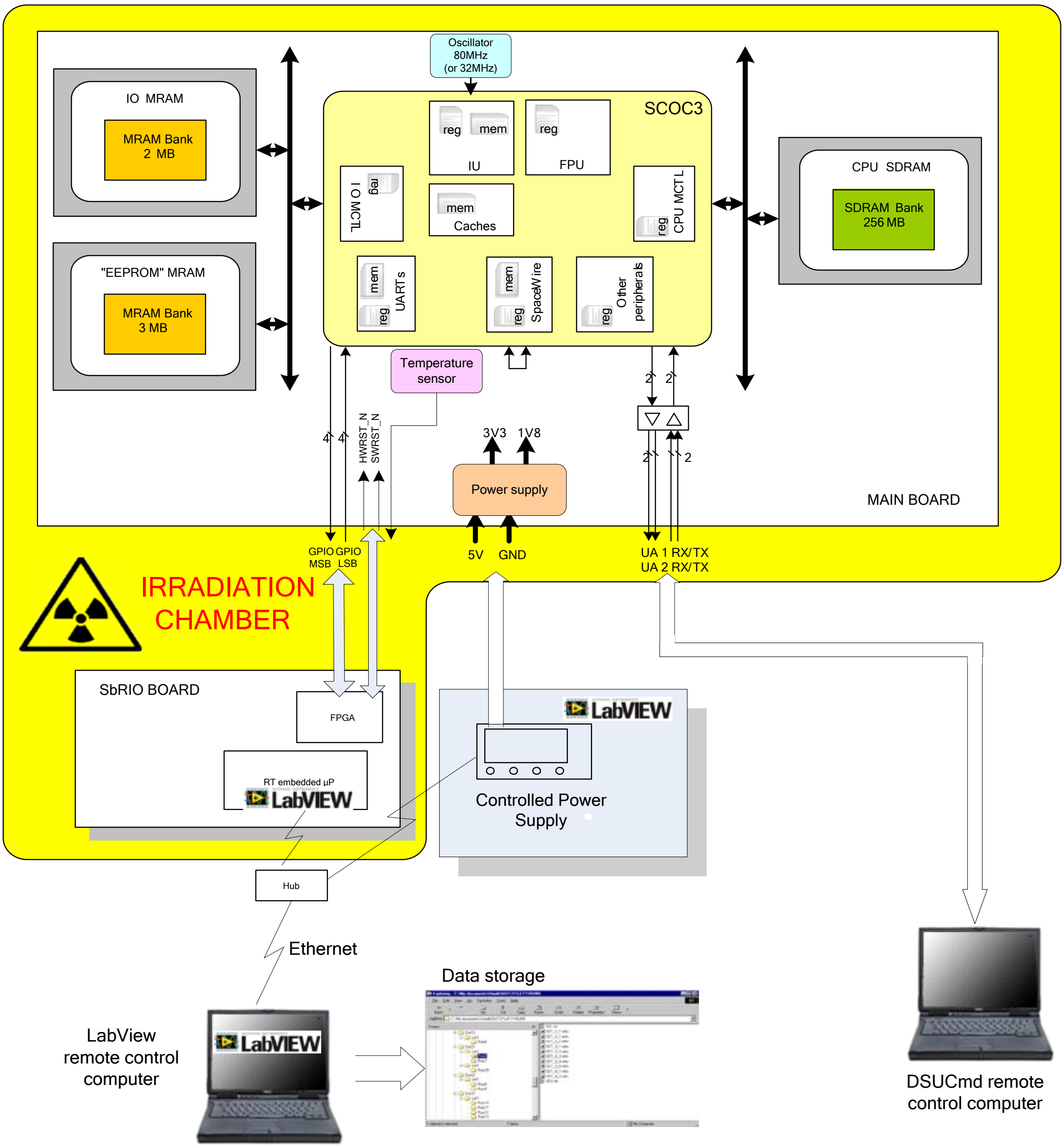

Figure 3: Test setup overview

The following picture shows the main board (fully populated) with the SBRIO board mounted on top.

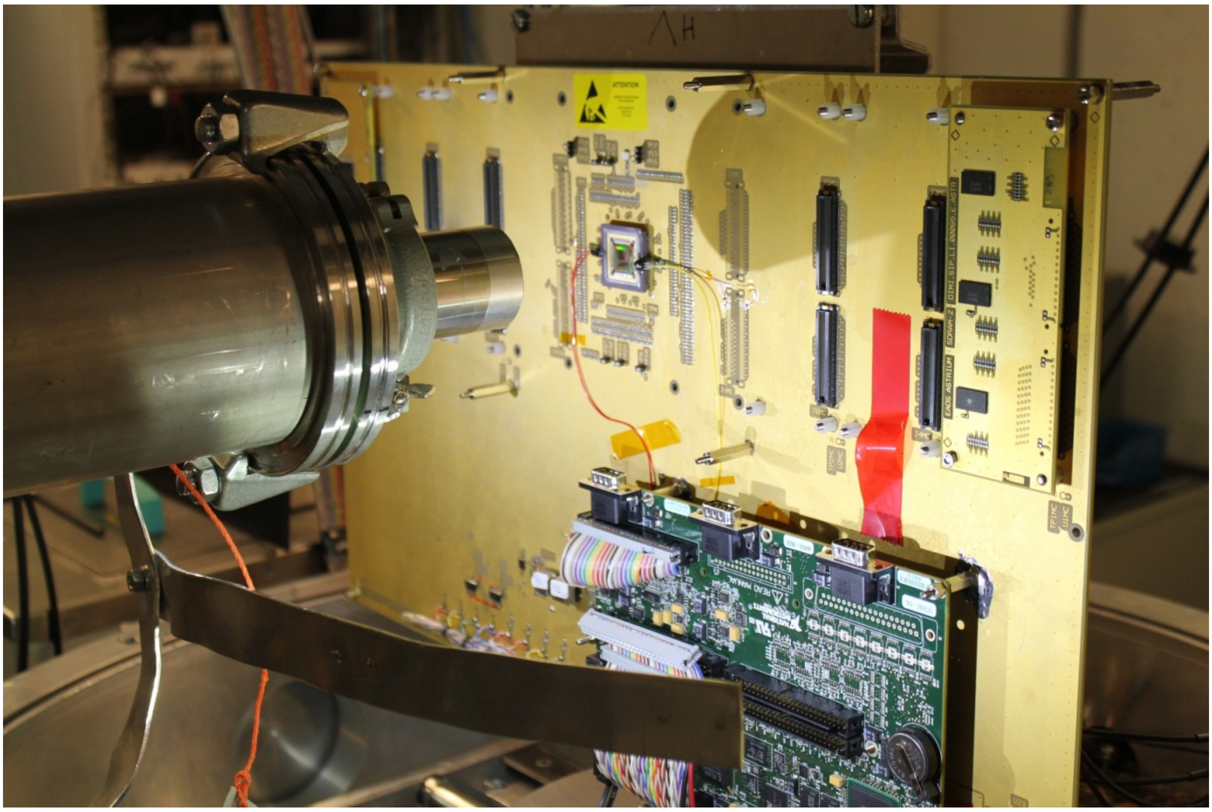

Figure 4: Main board mounted on beam installation, SCOC3 package opened

6.3 TEST CONDITIONS

The number of parts tested was two SCOC3 prototype ASICs.

Tests were carried out in free air condition since the board could dissipate a few Watts, and the original board design doesn't offer sufficient heat sink capabilities for operation under vacuum. The LET-range characteristics of used ions was corrected consequently (refer to Figure 2).

The baseline is fluxes between 100 and 5000 particles/cm²/s, and exposition time chosen to collect the necessary number of events. When no events occur, irradiation is stopped once fluence reaches at maximum 1e6 /cm² [AD1].

The tests have been done at room temperature (25°C), at nominal voltage for the first device, and as close as possible to the minimum voltage for the second device (limitation due to the serial bus communication).

The tests have been run at maximum frequency (80MHz for CPU and 40MHz for IO), and some tests have additionally been run at 32MHz (32MHz for both CPU and IO).

6.4 TEST PROCEDURE

The test procedure was to run the complete set of tests on the first ASIC, then only a few critical measures (test&LET pairs) were selected for the second ASIC to check the results consistency.

The LETs have been chosen according to the estimated cross-sections of the tests (see §9 of AD4).

For each test, the test itself, as well as a bootloader have been stored in MRAM with the DSU PC. Thus the ASIC booted and ran the test automatically (without manual intervention) at each power-on or reset.

After the radiation test, the estimated cross sections have been compared with the cross sections computed from the test results, for each LET.

7 HEAVY ION EXPERIMENTAL RESULTS

7.1 CALCULATION OF SET/SEU CROSS SECTIONS

The cross-sections were calculated as follows : **σ**(LET) = N/F

where :

- σ is the SET Cross-section (cm²), expressed as a function of the Heavy Ion LET
- LET is the Linear Energy Transfer $\left(\frac{1}{\rho}\frac{dE}{dx}\right)$, in MeV.cm²/mg
- N is the total Number of SET/SEU
- F = Fluence (part./cm²) (corrected according to the incident angle if any).

The minimum of fluence required is 10^6 part/cm², if no event detected.

As a first approach, the LET threshold is defined as the minimum LET value at which no event occurs at a fluence of 10^6 particle/cm².

7.2 SEE RESULTS

7.2.1 APB Registers

This test checks periodically the most number of registers on each APB bus. For each register tested, its current value is compared with its reset value. A pulse on GPIO output is sent to count the event if a difference is detected. The cache is disabled during this test. The IU Register File memory protection is activated during this test.

7.2.1.1 APB Registers, SEE results

The sensitivity curves is presented hereafter.

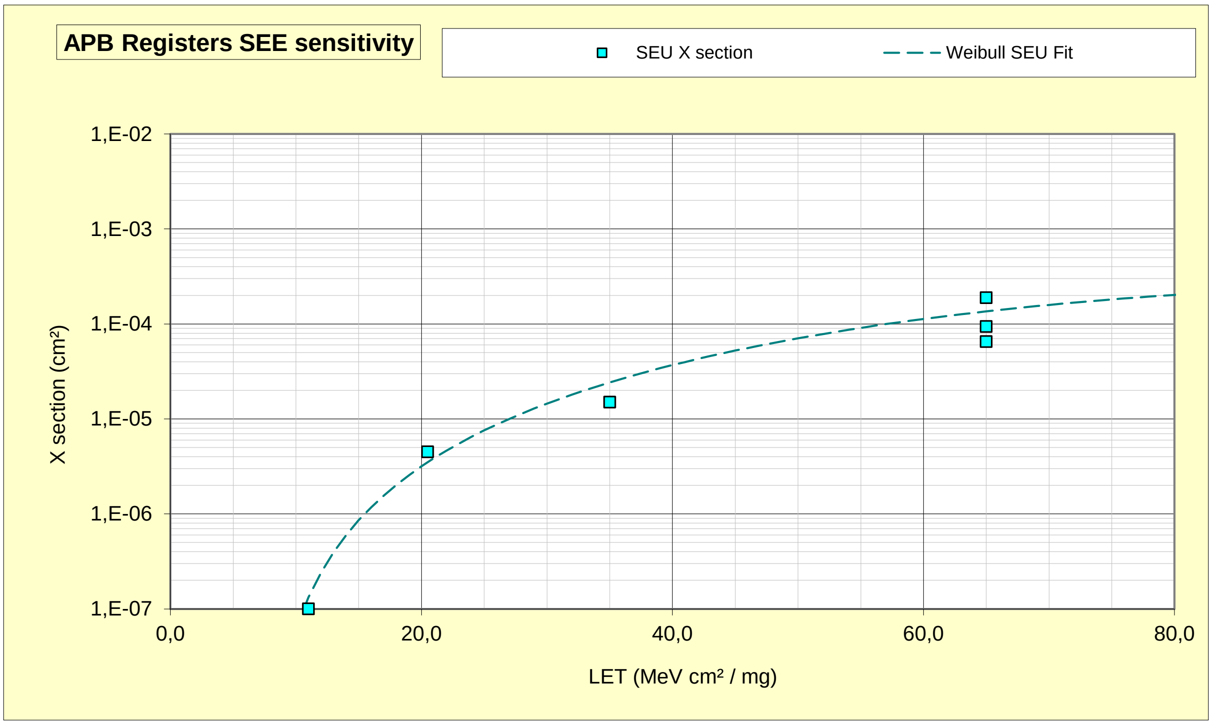

Figure 5: SEE sensitivity for SCOC3 APB registers

	SEU
σ sat *(cm²)*	3.0 E-04
LET th *(MeV cm²/mg)*	7
S	2.7
W *(MeV cm²/mg)*	70

Table 2: Weibull parameters

7.2.2 LEON3 Caches (Instruction/Data)

This test checks the four caches (2x64Ko) used by LEON3. The caches are disabled and all instructions and data are read from CPU RAM. The cache parity detection is not active during the test. The IU Register File memory protection is activated during this test.

7.2.2.1 LEON3 Caches, SEE results

The sensitivity curves is presented hereafter.

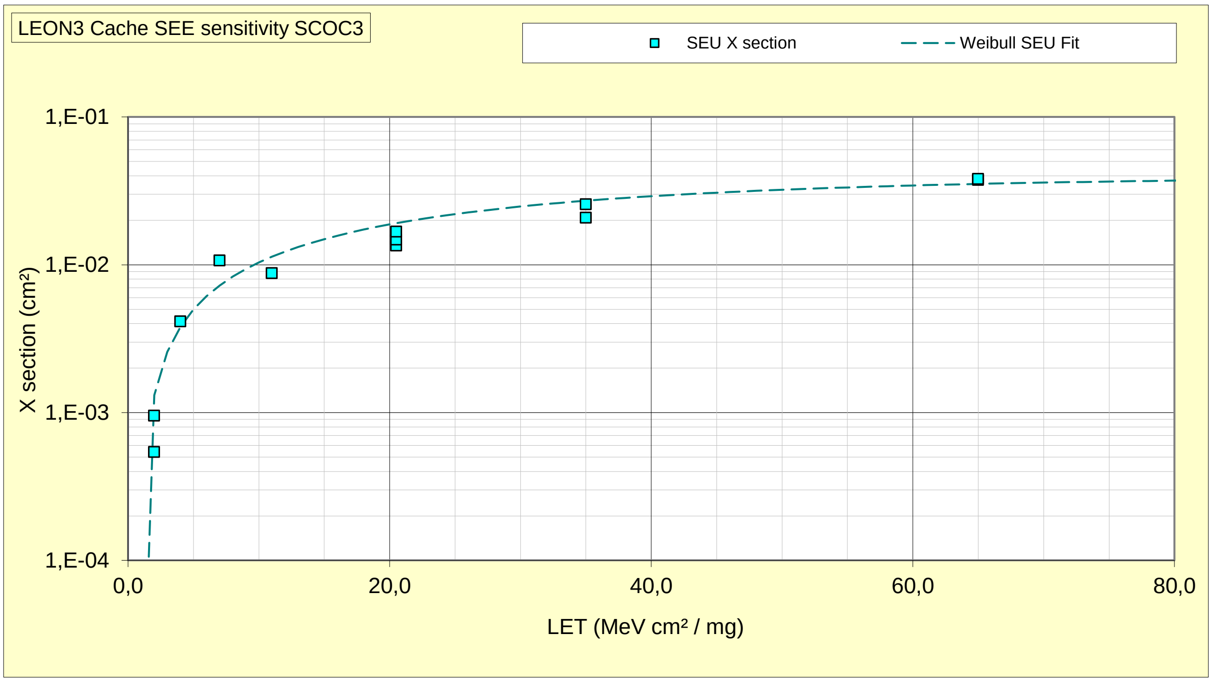

Figure 6: SEE sensitivity for LEON3 Caches

	SEU
σ sat *(cm²)*	4.0 E-02
LET th *(MeV cm²/mg)*	1
S	1
W *(MeV cm²/mg)*	30

Table 3: Weibull parameters

Remark: for this test, the SEE cache protection is deactivated.

7.2.3 LEON3 IU Registers

This test checks the internal registers of LEON3. The LEON3 is idle / in debug mode, no instruction is executed. This test is directly run by Unit Tester with Read/Write commands through DSU UART. The IU Register File Memory protection is not active during the test.

7.2.3.1 LEON3 IU Registers, SEE results

The sensitivity curves are presented hereafter.

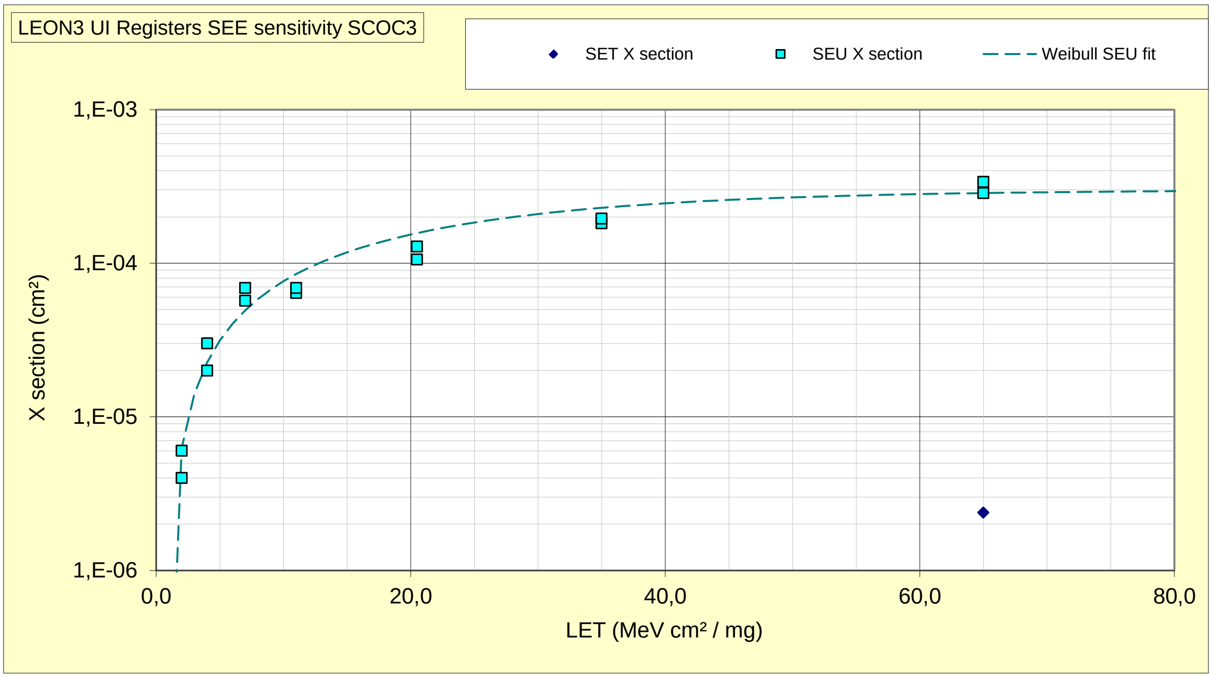

Figure 7: SEE sensitivity for LEON3 IU Registers

	SEU
σ sat *(cm²)*	3.0 E-04
LET th *(MeV cm²/mg)*	1
S	1.2
W *(MeV cm²/mg)*	25

Table 4: Weibull parameters

Remark: for this test, the IU Register File memory protection is deactivated.

7.2.4 LEON3 FPU

This test checks the FPU of LEON3. During the irradiation a Whetstone program is running in loop, arithmetic results are compared with nominal results. The IU Register File memory protection is activated during this test. This test was run in 3 configurations:

- 80MHz and caches disabled
- 80MHz and caches activated
- 32MHz and caches activated

7.2.4.1 LEON3 FPU, SEE results

The sensitivity curve is presented hereafter.

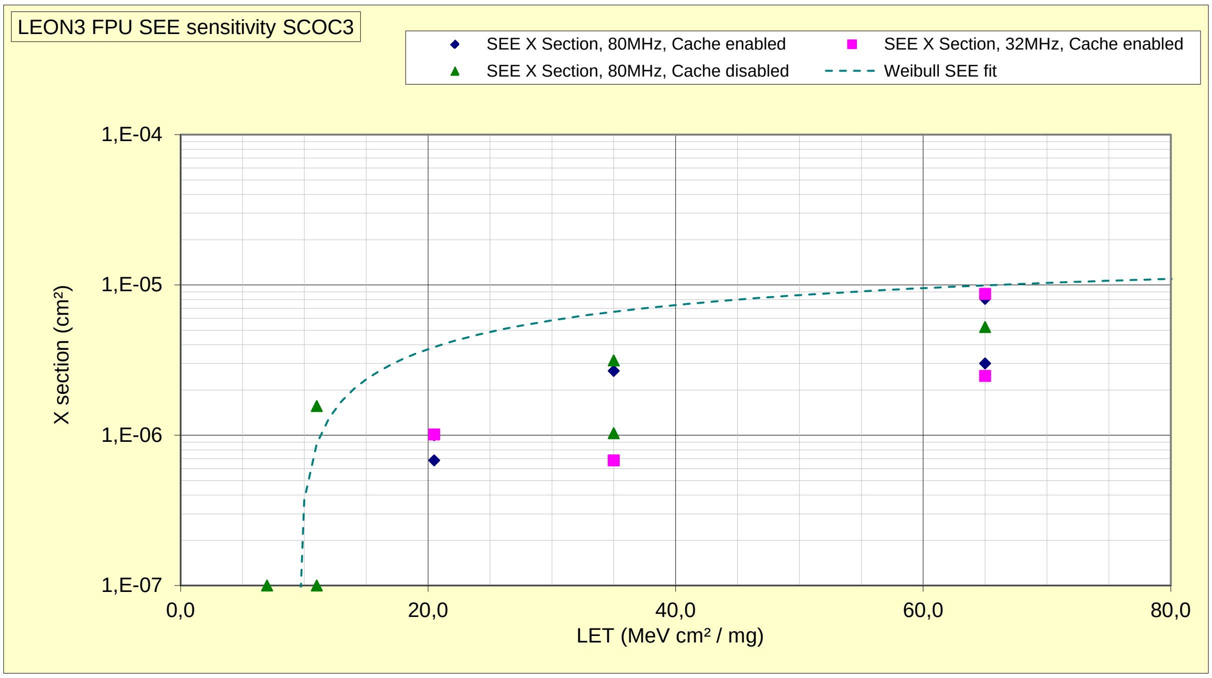

Figure 8: SEE sensitivity for LEON3 FPU

	SEE
σ sat *(cm²)*	1.5 E-05
LET th *(MeV cm²/mg)*	9.5
S	0.8
W *(MeV cm²/mg)*	50

Table 5: Weibull parameters

7.2.5 Spacewire

This test checks the Spacewire link between INTTX and INTRX. The RMAP mode and Data mode is checked with frequency taken from the PLL, this loop is repeated during emission of heavy ions beam. The cache is disabled during this test. The IU Register File memory protection is activated during this test.

7.2.5.1 Spacewire, SEE results

The sensitivity curve is presented hereafter.

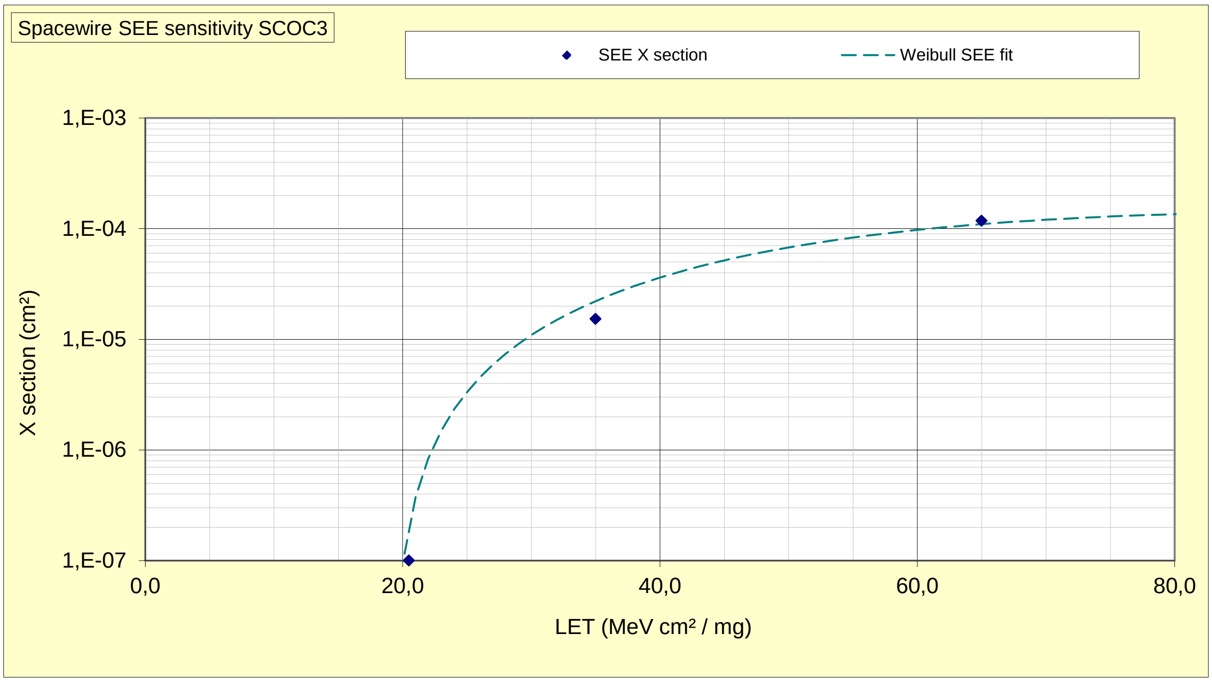

Figure 9: SEE sensitivity for SCOC3 Spacewire

	SEE
σ sat *(cm²)*	1.5 E-04
LET th *(MeV cm²/mg)*	19
S	2
W *(MeV cm²/mg)*	40

Table 6: Weibull parameters

7.2.6 Timers

This test checks the three 32-bit GPTimers and the 64-bit Counter. Each GPTimer is configured with specific values to generate periodic pulses on GPIO outputs. The caches are disabled during this test. The IU Register File memory protection is activated during this test.

7.2.6.1 Timers, SEE results

The SCOC3 Timers test was very little sensitive so the test has been only done with the first ion cocktail and one device . Due to the low amount of events and experimental data points, no reliable Weibull fit can be derived.

7.2.7 Datation

This test activates datation module to generate ITs and pulses on GPIOs. The test uses the internal clock of SCOC3 to synthesize datation counters (SCET). The caches are disabled during this test. The IU Register File memory protection is activated during this test.

7.2.7.1 Datation, SEE results

The SCOC3 Datation test was very little sensitive so the test has been only done with the first ion cocktail and one device . Due to the low amount of events and experimental data points, no reliable Weibull fit can be derived.

8 CONCLUSION

8.1 SEE SUMMARY

Major results are:

8.1.1 SEL / FAILURE

At nominal voltage and temperature (<40°C) conditions, SCOC3 is unsensitive to SEL and to Electrical Failure up to 65 Mev.cm2/mg.

8.1.2 SEU

The cross section Weibull parameters of each test are summarized in the table below:

	APB test	Cache test	IU Registers test	FPU test	SpaceWire test
σ sat *(cm²)*	3,00E-04	4,00E-02	3,00E-04	1,50E-05	1,50E-04
LET th *(MeV cm²/mg)*	7	1	1	9.5	19
S	2,7	1	1,2	0,8	2
W *(MeV cm²/mg)*	70	30	25	50	40

The estimated error rate per day for the whole SCOC3 is summarized in the table below for 2 orbits:

LEO	GEO
3,97E-07	**5,62E-06**

For Geostationary mission, the rate calculation takes into account 16 days in solar flare condition, 15 years in quiet condition and at 36000km.

For Low Earth Orbit mission, the rate calculation takes into account 8 days in solar flare condition, 10 years in quiet condition, 98° of inclination and at 800km.

8.2 POWER SUPPLY AND FREQUENCY VARIATION

No significant cross section difference was detected between functioning with nominal power supplies (IO at 3.3V and core at 1.8V) and with degraded power supplies (IO at 3.15V and core at 1.68V).

No significant cross section difference was detected between functioning at 80MHz and 32MHz and as a consequence there is no indication for the presence of SET effects on the data path.

DIFFUSION LIST

	WHOLE DOCUMENT		
	Action	**Information**	
Roland Weigand (ESA)		x	
Veronique Ferlet-cavrois (ESA)		x	
Franck Koebel		x	
Aurélien Lefèvre	x		
Christian Binois	x		
Duc Dam	x		
Marc Souyri		x	
Jean-Marc Taine		x	
Rémi Cissou		x	
Aminata Carvalho		x	
Thierry Beutier		x	
Damien Leroy		x	
Renaud Mangeret		x	
Mathias Marinoni		x	