An In-Depth Description of the Radiation Data Package for the QLS1046-Space Edge Processing Module

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Agenda

- Introduction
- Focus on QLS1046-Space
- Radiation Testing Strategy
- LS1046 SEE Radiation Testing
- DDR4 SEE Radiation Testing
- TID Verification
- Conclusion

Teledyne e2v Data Processing Solutions

Addressable Projects & Target Applications in Space

Sensing
Optical, IR, Radar

Payload RF
(Signal Chain)

Payload On-board Processing (AI, ML)

Satellite Bus
Processing and Routing of data

Power Management

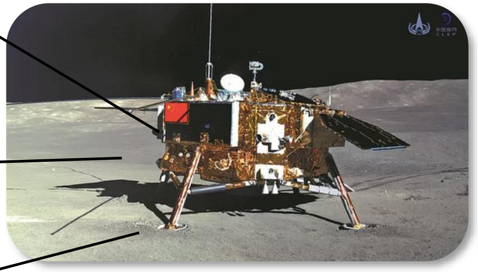
Propulsion

Positioning / Telemetry
GPS / Star Tracker

Satellite Control / Monitoring / Watchdog (Platform)

Satellites: Earth Observation, Communication, Intelligence Gathering …

On Board computers



Avionics

Robotics

Data Gathering, Internet on the Moon

Vehicles: Manned, Cargo, Launch, Landing
Space Stations & Gateways

Legenda : Addressable with Teledyne e2v Data Processing Solutions

High Level Processing Roadmap

R&D phases engaged to anticipate Next Gen Space computing needs

16x ARM® Cortex®-A72

Pin - Pin Compatibility 4GB & 8GB

LX2160-Space

DDR4 8GB

*Objective : Serve Space Projects from **2024 onwards***

Shipping Now

Quad ARM® Cortex®-A72

15mm x 20mm x 1.92mm

LS1046-Space

DDR4T04G72M

QLS1046-Space

Objective : Serve Space Projects Today

Mass Production

Single/Dual Core PowerArchitecture®

PC8548

P2020

*Serving Space Compute Intensive Market, **QML-Y & NASA Grades***

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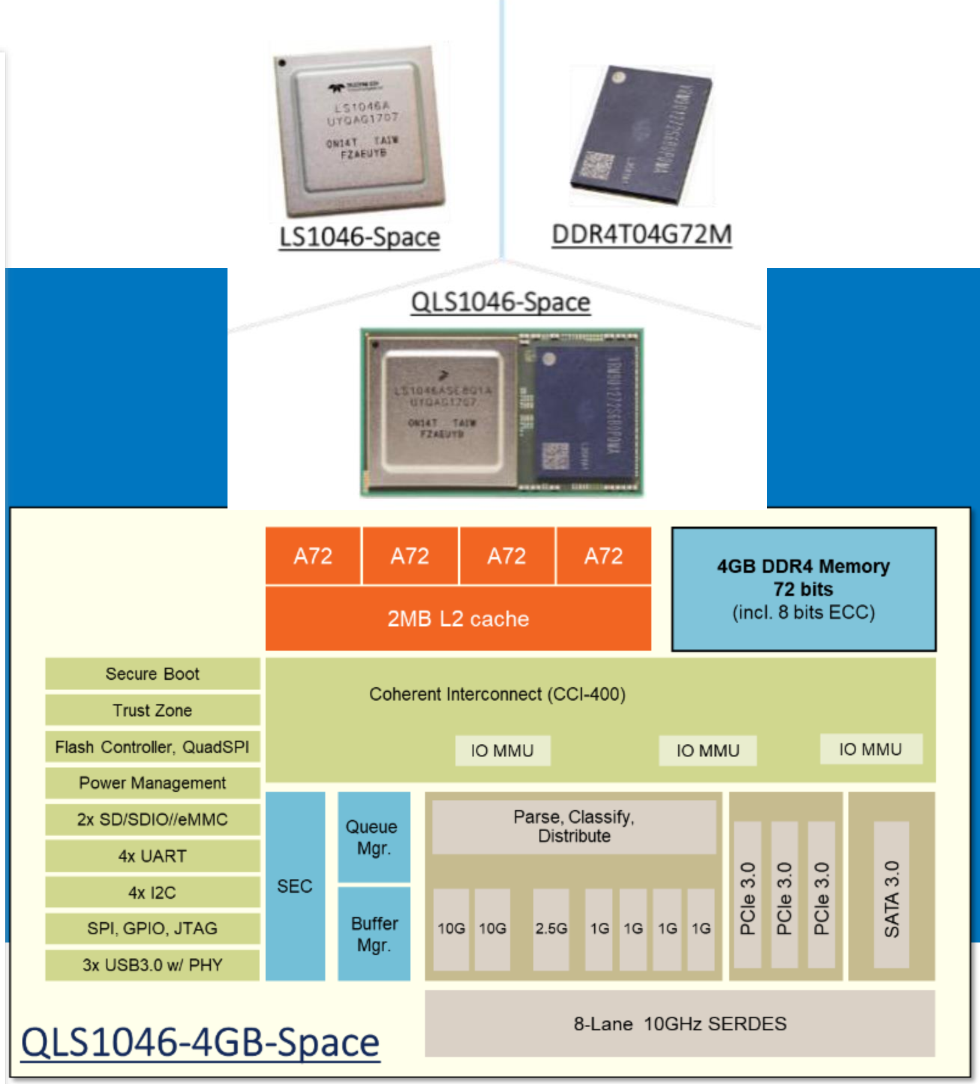
QLS1046-Space for Edge Computing

- Combination of LS1046-Space & DDR4T04G72 memory
- Heavy computing capabilities in ultra-compact design:
  - Quad-core 64-bit Arm® Cortex A72: Up to 30kDMIPS with NEON vector processing units (56GFLOPs)
  - Integrated 4GB x72bit DDR4 memory up to 2.4GT/s rate
  - 2MB total L2 cache, 1-10GbE, PCIe 3.0, UARTs, SPI, I²C, ...
  - Highly compact (44x26mm) and power efficient
- Radiation tolerant and Space qualified (NASA EEE-INST-002 - Section M4 – PEMs & ECSS-Q-ST-60-13C)



Teledyne e2v Compute Intensive Rad Tol solutions

Teledyne e2v Value Proposal

- Supplier of Advanced Radiation Tolerant Space Compute Intensive solutions
  - Bringing **existing COTS solutions** to **Space environments**
    - *Characterizations, Space Screening, Qualifications*
    - *Radiation Characterizations & Mitigations recommendations*

- Fully characterized, tested & qualified Space Compute Intensive solutions
  - Highest grade Characterizations, Testing & Qualifications – From Long lasting partnership with NXP
    - *Access to same platforms (test vectors, burn in platforms), same testers*
    - *Leading to highest quality testings and same test coverage*
  - Fully Tested and characterized in Radiation (TID, SEE Heavy Ions, Protons & mitigations)

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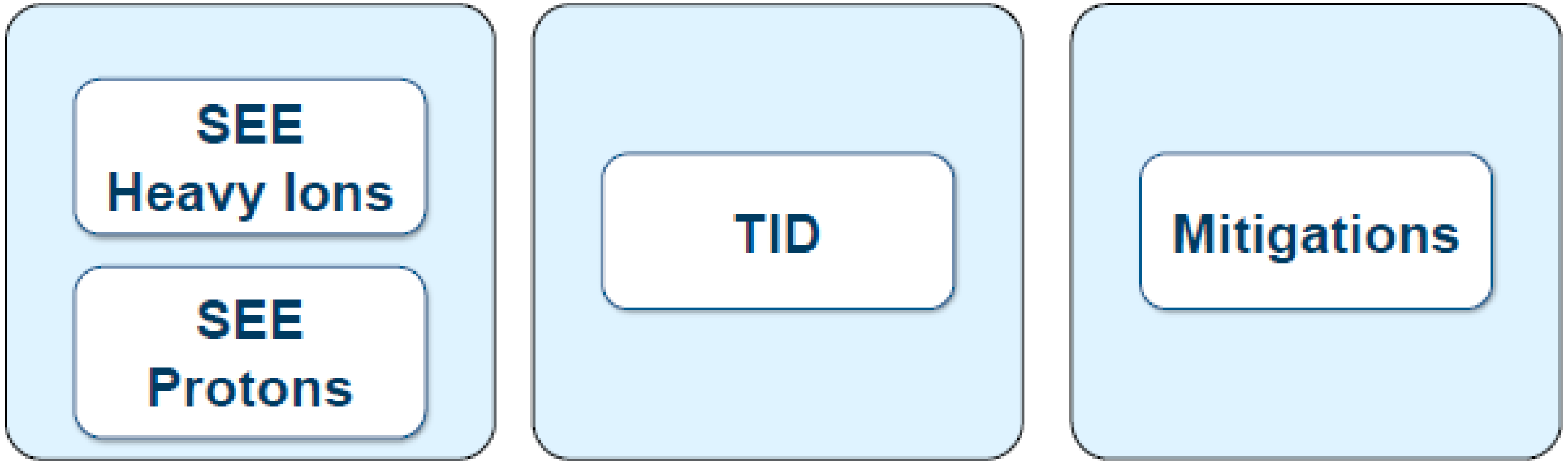
Teledyne e2v's Strategy for Radiations

- "Radiation Tolerant (RadTol)" Teledyne e2v's definition:
  - No damage due to radiations
  - Can be subject to SEU (upsets) or SEFI (functional interrupts)

- SEE (Single Event Effects)
  - SEL immunity verification
  - SEU / SEFI characterization
- TID testing
  - Verifies lifetime in Space
- Mitigations techniques

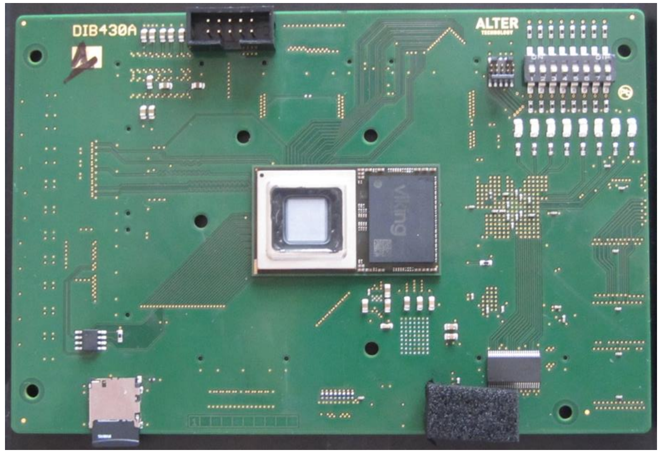


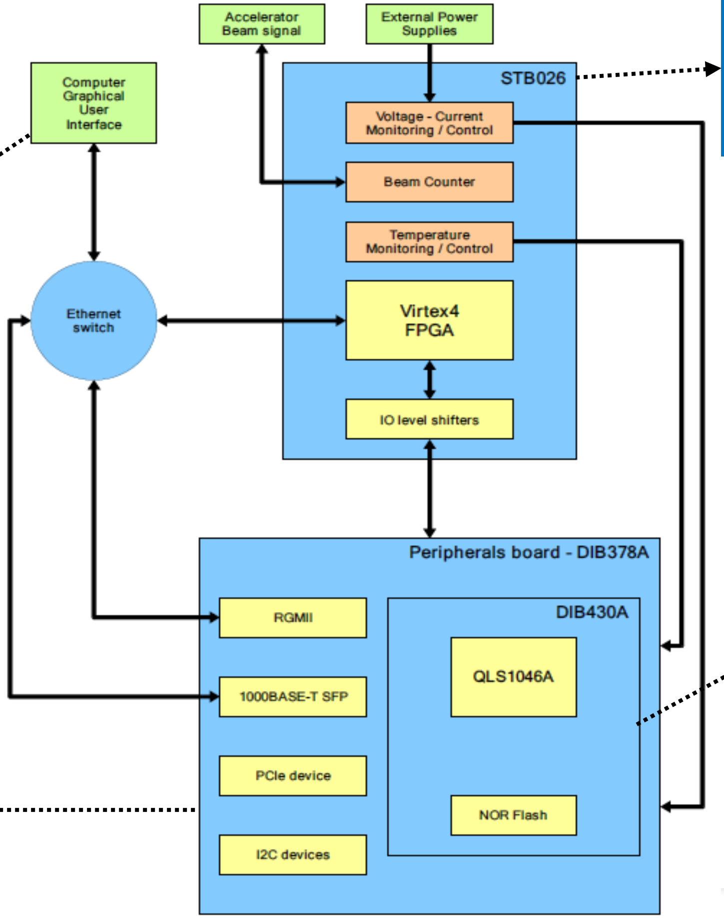
- <u>For QLS1046-Space: Teledyne e2v performed tests of LS1046 processor and DDR4 one at a time</u>

Teledyne e2v's Strategy for Radiations

- Based on specifically designed test HW and SW:
  - Permits to select the right testing configuration and relevant peripherals
  - Allows to monitor or control currents/voltage/temperature
  - Simplifies interface with general monitoring system
  - …

Example of a QLS1046-Space test setup





Log data (voltage/current)

Reset/reboot the board latchup management

Manage test setup

Store the data timestamped by FPGA

Essential functions (Memories,Clock, boot sequence, boot source…)

Peripherals

Performs the interfaces with the rest of the system

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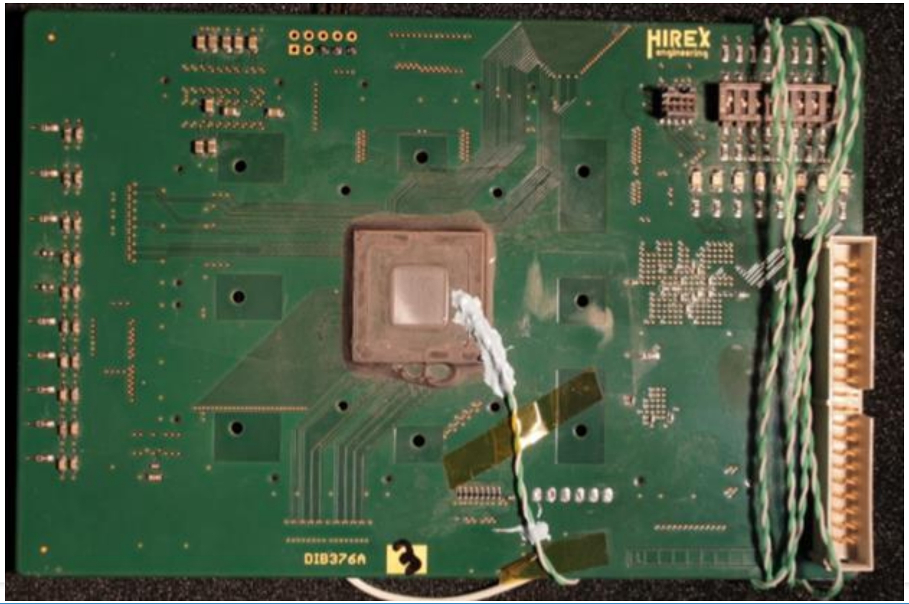
LS1046 SEE Radiation Testing

SEL Results

- 3 devices tested
- At max temperature (125°C) & max operating voltage
- Fluence of 1e7 ions/cm²
- <u>No SEL detected up to 62 MeV/mg/cm²</u>



Test performed at RADEF facilities

Effective LET at surface

16.3 MeV/n cocktail in air			
Ion	Range	LET at surface	LET in air and through 75µ of Silicon
	microns	MeV/(mg/cm²)	MeV/(mg/cm²)
17O6+	481	1.52	1.8
20Ne7+	360	2.3	2.6
40Ar14+	264	7.2	8
57FE20+	214	13.3	16
89Kr29+	185	24.5	32
126Xe44+	157	48.5	62.5

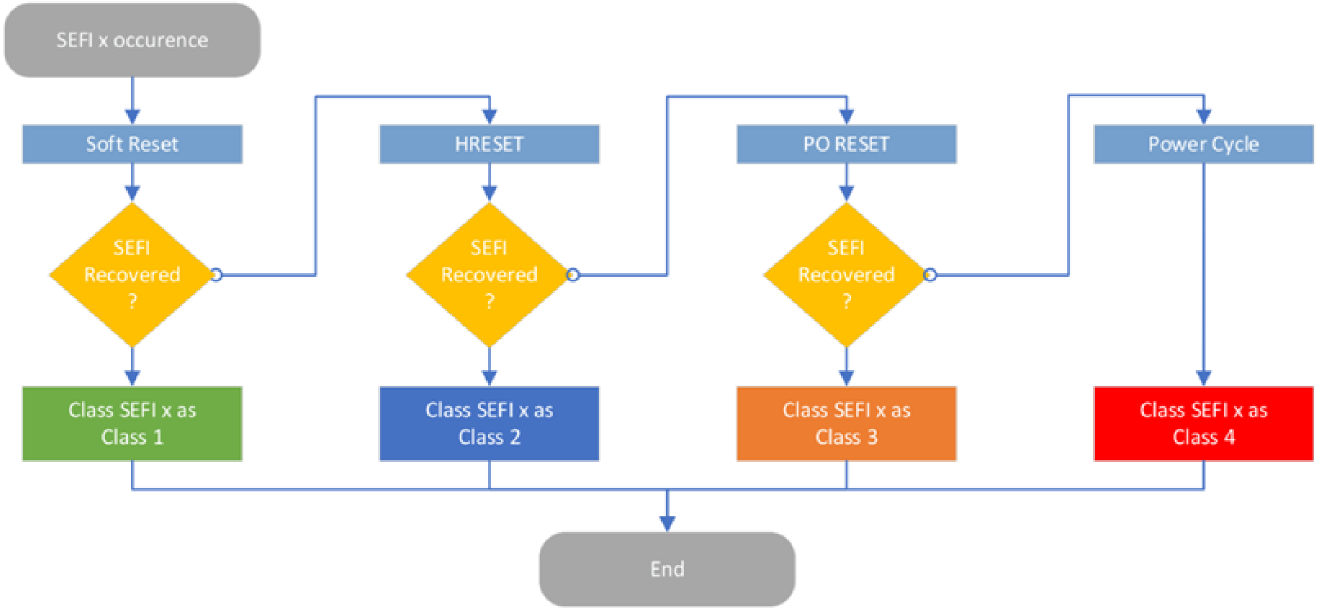
LS1046 SEE Radiation Testing

SEFI/SEU Characterization under Heavy-Ions

- FPGA monitors CPU activity and takes actions when SEFI : Algorithm to classify the SEFI event by recovering method

Table 6: SEFI rates on 3 orbits for 3 solar conditions, in n° of SEFI per day

	GEO	ISS	Proba 2
Solar min	$1.07.10^{-3}$	$1.55.10^{-4}$	$3.67.10^{-4}$
Worst day	7.63	$2.70.10^{-3}$	1.69
Worst 5min	28.5	$9.62.10^{-3}$	6.31



- <u>Takeways:</u>
  - <u>No power cycle required to cure SEFI</u>
  - <u>1 SEFI per 1000 days in GEO normal conditions</u>

Table 9: SEU rates on 3 orbits for 3 solar conditions, in n° of SEU device per day

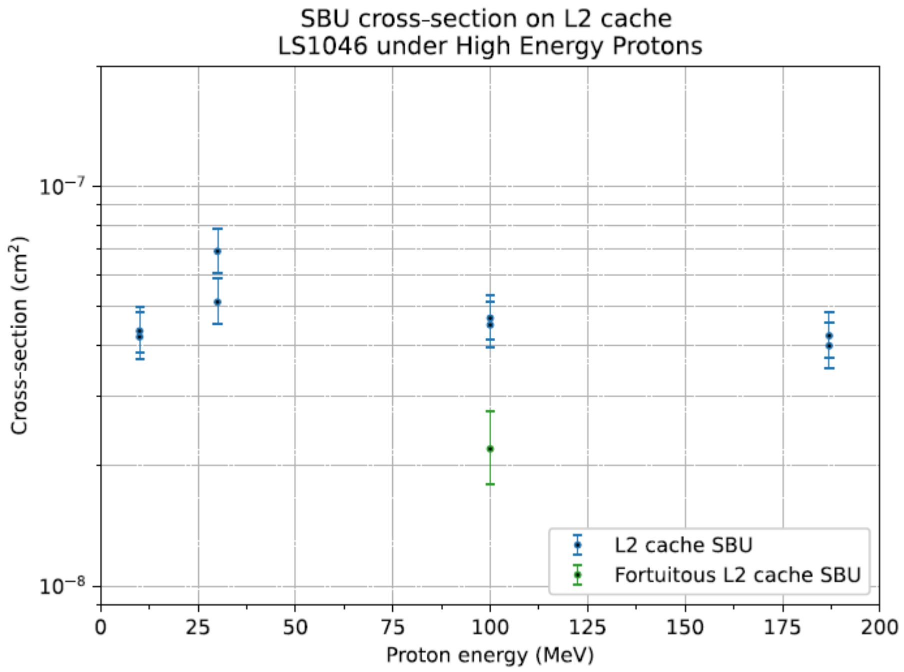
	GEO	ISS	Proba 2
Solar min	$1.96.10^{-1}$	$2.68.10^{-2}$	$6.61.10^{-2}$
Worst day	$1.56.10^{2}$	$2.06.10^{-1}$	$3.49.10^{1}$
Worst 5min	$5.80.10^{2}$	$6.94.10^{-1}$	$1.30.10^{2}$

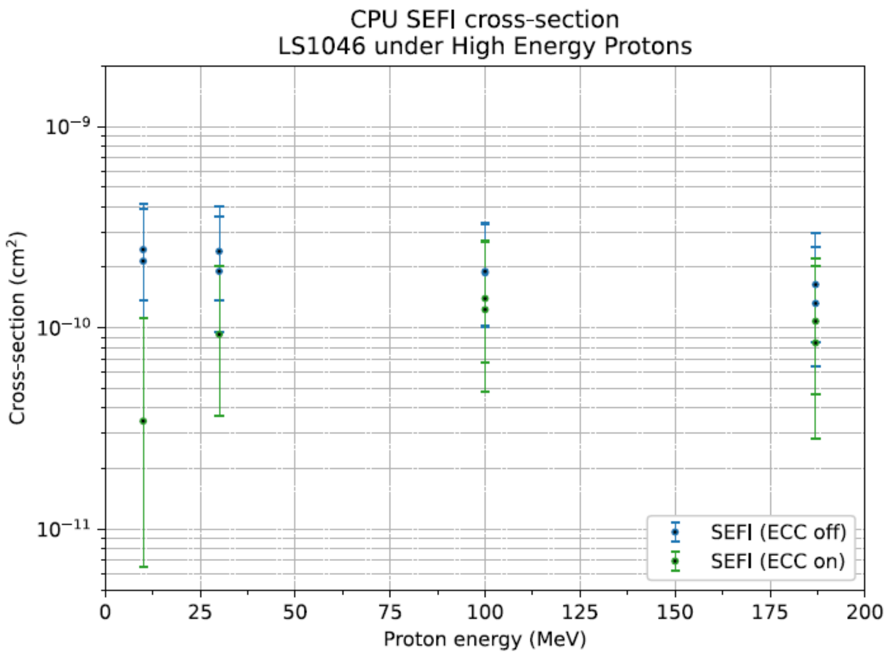
- SEU events characterized on L2 cache & On-chip RAM
- Peripherals were also characterized SEU/SEFI

LS1046 SEE Radiation Testing

Protons Results

- ❖ 2 samples tested
- ❖ Proton beam up to 190MeV
- ❖ On-chip RAM and L2 cache were tested





- ❖ <u>ECC protection on L2 cache corrects SBU !</u>

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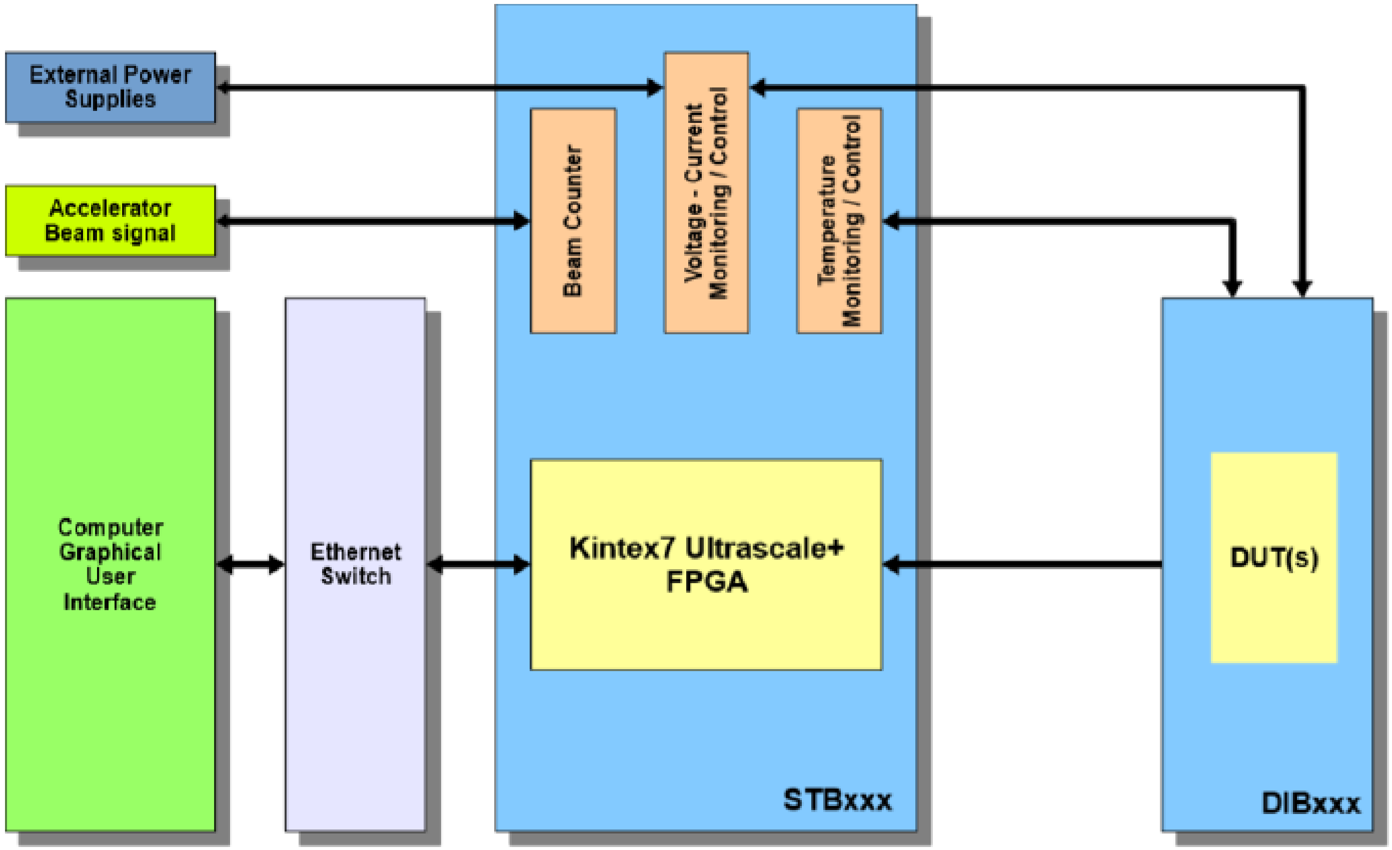
DDR4 SEE Radiation Testing

Test Setup

- DDR4 tested in 2 ways :
  - With QLS1046 test setup
  - Single die setup for in-depth testing

- Single die setup:
  - Connects a SODIMM daughter board (DUT)
  - Memory is interfaced directly with a FPGA
    - Gets full-visibility on the SEE
  - Power supplies monitored to detect SEL

Single die test setup



DDR4 SEE Radiation Testing

SEL Results

- At 95°C operating temperature and max operating voltage
- Fluence up to 1e7 ions/cm²
- <u>No SEL detected up to 60 MeV/mg/cm²</u>

Test performed at RADEF facilities

Effective LET at surface (based on part thinning)

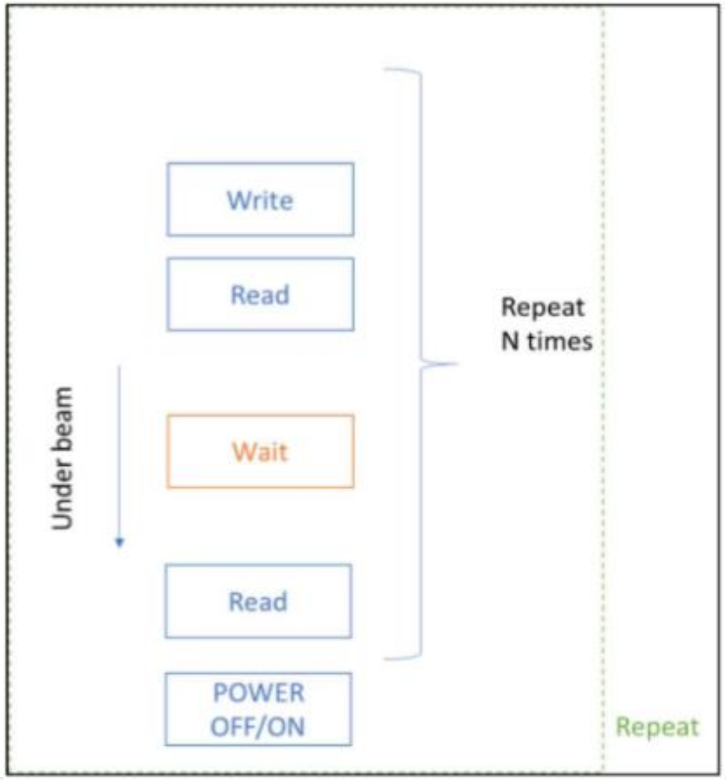
				Back irradiation LET Die Silicon thickness SRIM 2013	
Ion	LET^{SRIM} at surface [$MeV.cm^2.mg^{-1}$]	Range [µm]	Beam energy [MeV]	70µ	80µ
$^{17}O^{6+}$	1.52	481	284	1.54	1.56
$^{20}Ne^{7+}$	2.3	360	328	2.6	2.65
$^{40}Ar^{14+}$	7.2	264	657	8.19	8.38
$^{57}Fe^{20+}$	13.3	214	941	15.69	16.17
$^{83}Kr^{29+}$	24.5	185	1358	30.06	31.12
$^{126}Xe^{44+}$	48.5	157	2059	60.88	63.07

DDR4 SEE Radiation Testing

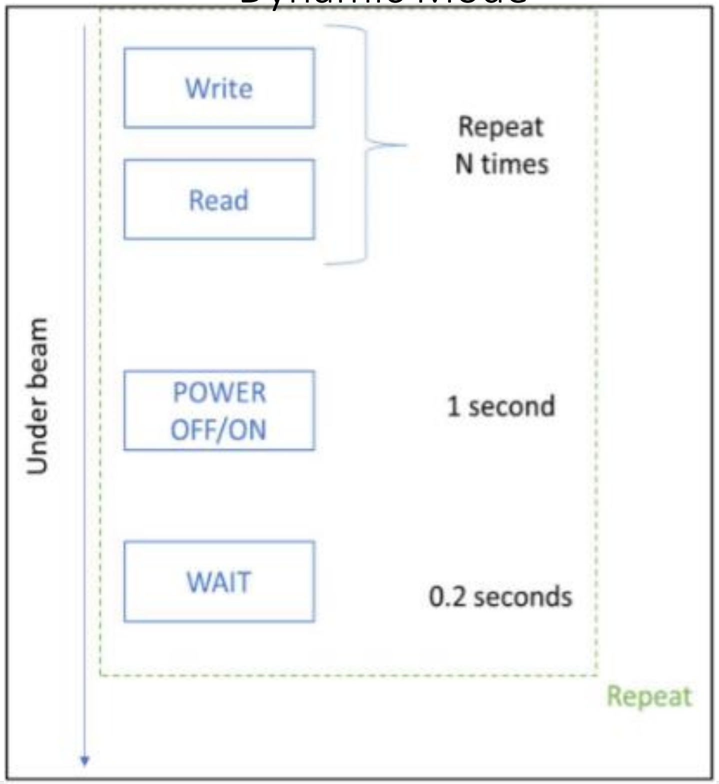
SEFI/SEU Characterization under Heavy-Ions

- Two ways of testing SEU:
  - Static: Memory not exercised under the beam
  - Dynamic: Memory is exercised under the beam

Static Mode



Dynamic Mode



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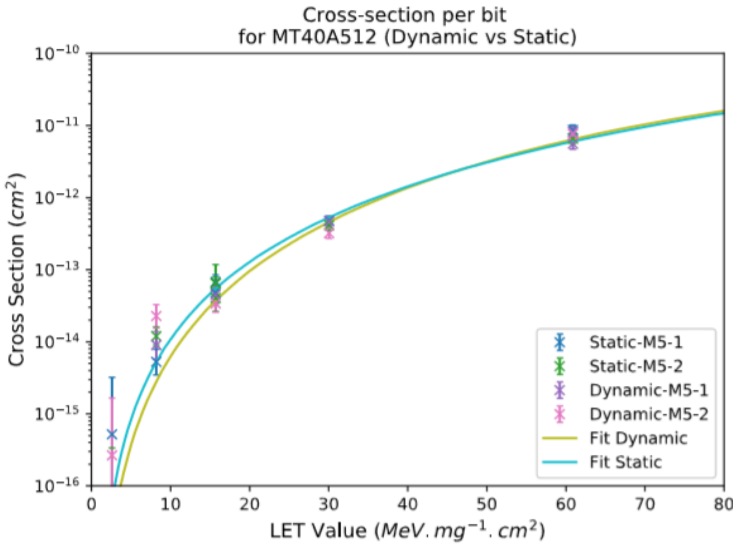
DDR4 SEE Radiation Testing

SEFI/SEU Characterization under Heavy-Ions

- SEU results:
  - <u>Similar results between static and dynamic mode</u>



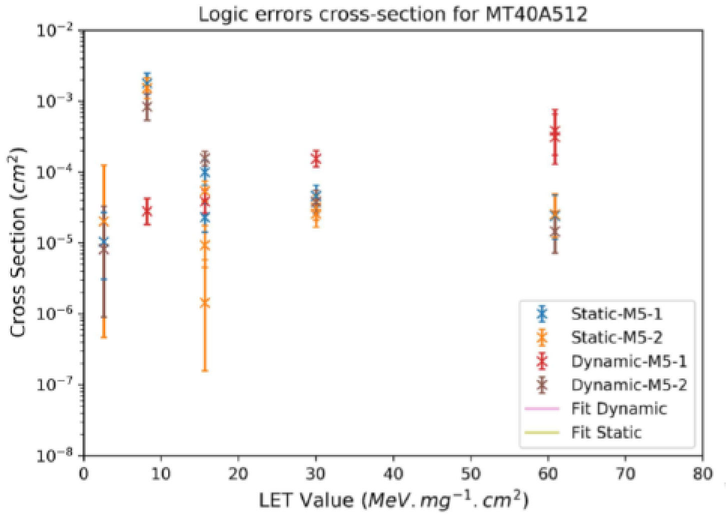
Weibull parameters (Static mode)

Parameter	Value
A	1.14E-10
x_0	0.5
S	3.43
W	141.29

Weibull parameters (Dynamic mode)

Parameter	Value
A	4.49E-11
x_0	0.5
S	3.79
W	98.87

- SEFI characterized and classified :
  - <u>DDR4 reset sufficient to clear SEFIs up to 25 MeV/(mg/cm²)</u>

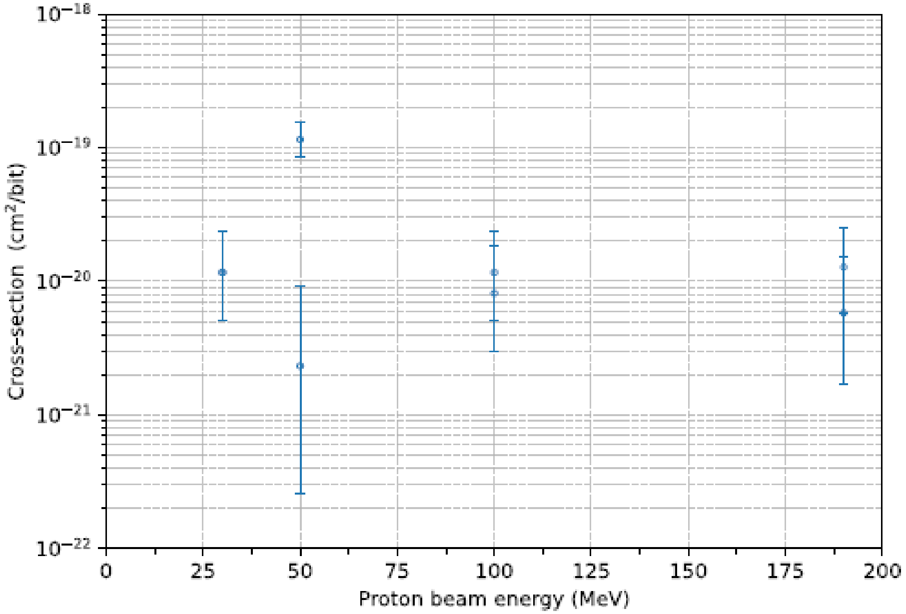


DDR4 SEE Radiation Testing

Protons Results

- 2 samples (tested in single die)
- Proton beam up to 190MeV

RUN	Proton energy (MeV)	Fluence (p+.cm^{-2})	Dose (krad)	Duration (s)	BoardID	Bits	Upsets	Upset cross-section (cm²/bit)	Row errors	Column errors
RUN001	100	1.00E+11	9.34	1477	6	8,589,934,592	7	8.15E-21	6770	692
RUN002	190	1.00E+11	6.00	1493	6	8,589,934,592	5	5.82E-21	5144	418
RUN006	190	1.00E+11	6.00	1418	7	8,589,934,592	11	1.28E-20	17505	448
RUN007	100	1.00E+11	9.34	1414	7	8,589,934,592	10	1.16E-20	12075	374
RUN010	50	1.00E+11	15.82	1498	7	8,589,934,592	99	1.15E-19	14595	287
RUN011	30	1.00E+11	23.63	1572	7	8,589,934,592	10	1.16E-20	10024	216
RUN012	30	1.00E+11	23.63	1429	6	8,589,934,592	10	1.16E-20	8148	392
RUN013	50	1.00E+11	15.82	1487	6	8,589,934,592	2	2.33E-21	8665	544



- Main takeways:
  - All upsets are SBU => corrected by ECC !
  - Low-sensitivity at all energies: in the range of 1e-20 cm²/bit
  - Logic errors (row and column) are mitigated by applying “reset” operation

TID verification

LS1046-Space & DDR4

- LS1046-Space
  - Dose up to 100 krad (Si)
  - 6 Samples biased ON using a dummy software
  - 6 Samples biased OFF (all pin connected to Ground)
  - Use of UltraFLEX equipment for electrical testing (Teledyne e2v industrial tester)
- DDR4T04G72
  - Dose up to 100 krad (Si)
  - 5 Samples biased ON
  - 5 Samples biased OFF (all pin connected to Ground)
- Successful results: LS1046-Space and DDR4T04G72 can sustain a dose of 100krad (Si)

Conclusion

- Quick recap:
  - Radiation testing strategy applied by Teledyne e2v on its edge processing devices
  - Presented the setups and main radiation results for QSL1046-Space:
    - LS1046-Space processor results,
    - DDR4T04G72 results,

- **QLS1046-Space offers a good radiation performance with a comprehensive set of data**
  - Detailed results available in radiation reports (available upon request)

Credits

- Teledyne e2v LS1046—Space project, on which QLS1046-Space is based, is supported by CNES (French Space Agency) through an ESA ARTES program

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QUESTIONS ?