COTS for space

Cristina Plettner
System Engineer Radiation, Airbus Bremen

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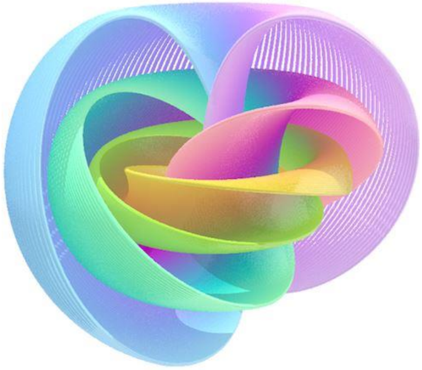
Overview

- My job in Airbus Defence and Space
- Space environment challenge (radiation, vacuum, thermal)
- EEE parts classification vs mission profile
- Need for commercial off the shelf in the context of Space 4.0
- Example of a COTS qualification campaign

System Engineer Radiation

Responsabilities: 4PI nuclear physics/engineering

Single Event Effects Testing



Space Weather Simulations
Interface with NASA

The system radiation specification
NASA/ESA

Radiation Analyses: rate calculations, implications on the system reliability.
ESA/NASA/Lockheed Martin

Design to requirements

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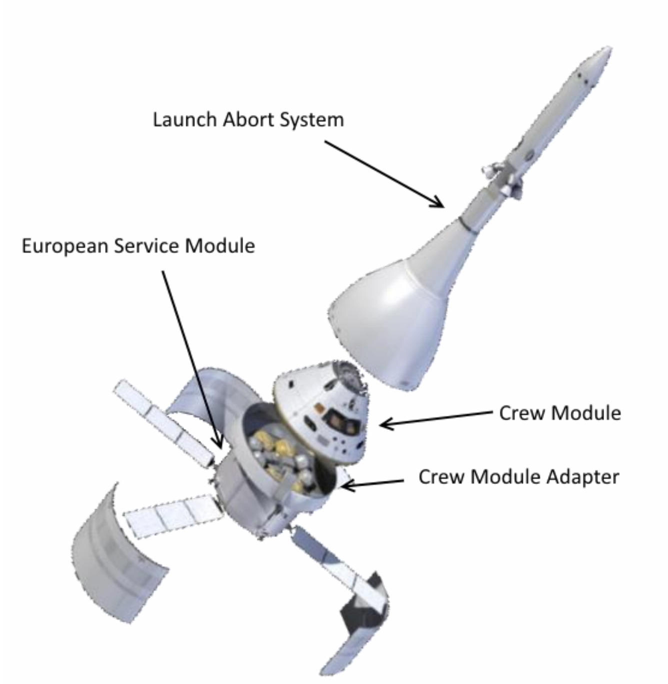
Orion Project



- Orion is the future NASA's spacecraft to send astronauts into space (Moon).

- The european contribution to Orion is the ***European Service Module (ESM)***
  - Developed by ESA and the prime contractor Airbus Defence and Space Bremen
  - Providing power generation, thermal control, gas and water, and propulsion to the crew module.

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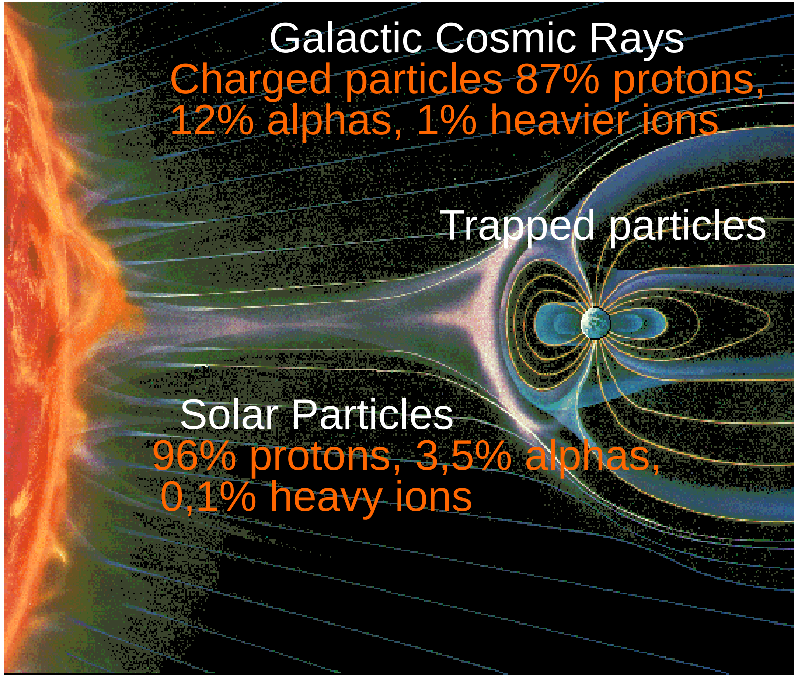
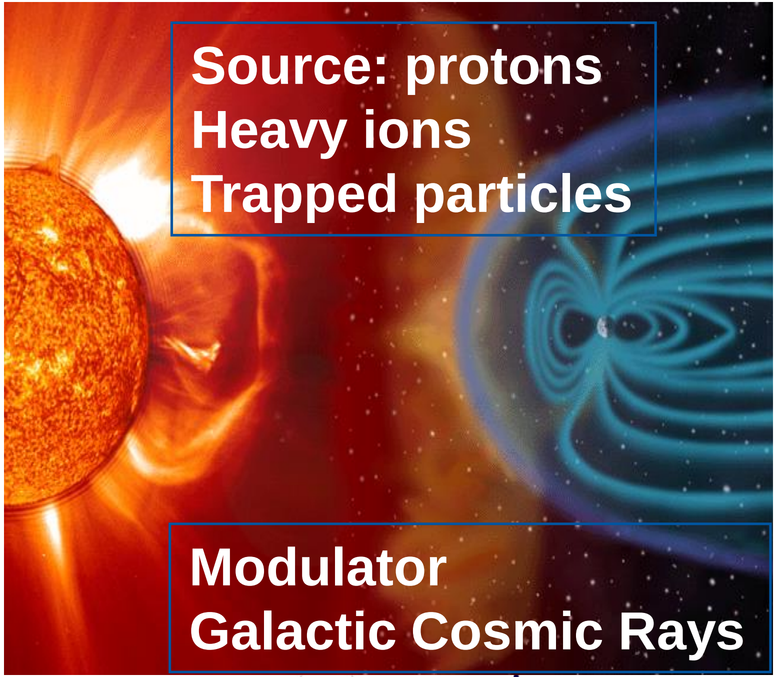
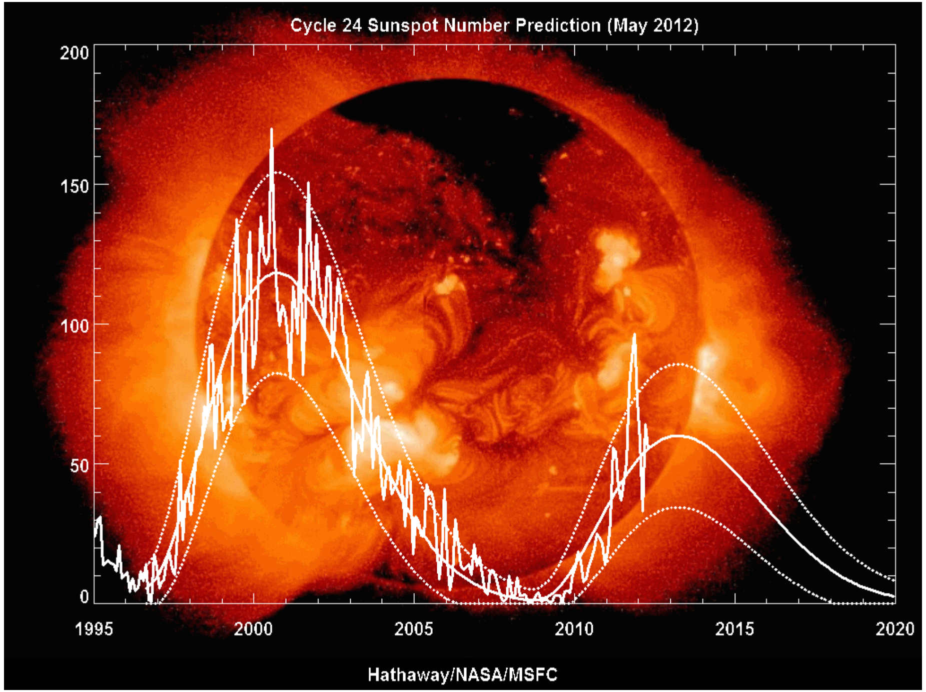
Space environment



Solar particle events





Solar wind: 500-750 km/s. Particles/s: 1E36 .
For a manned flight, a major solar storm has to be included-

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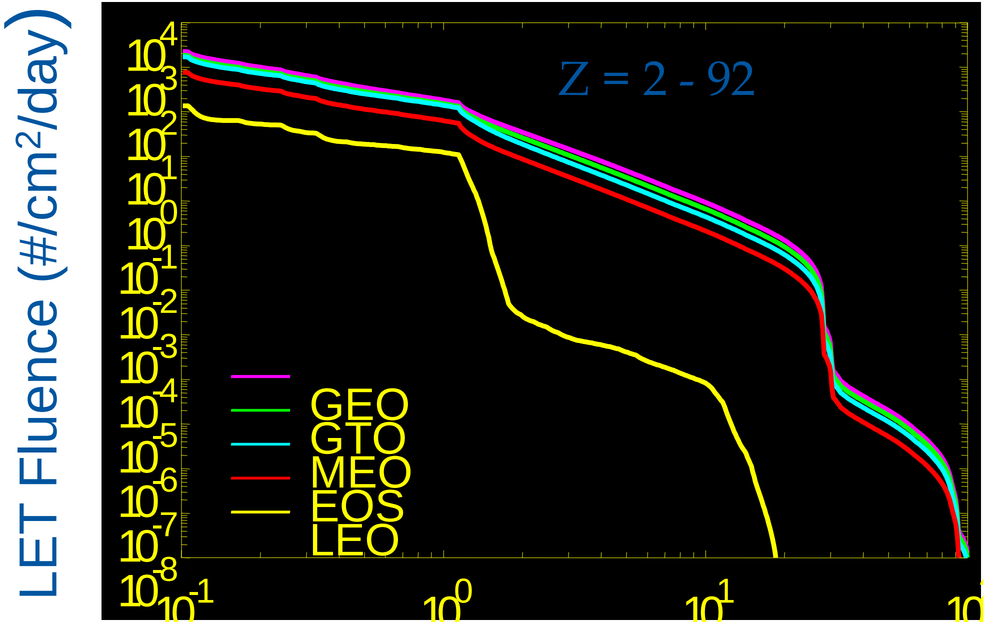
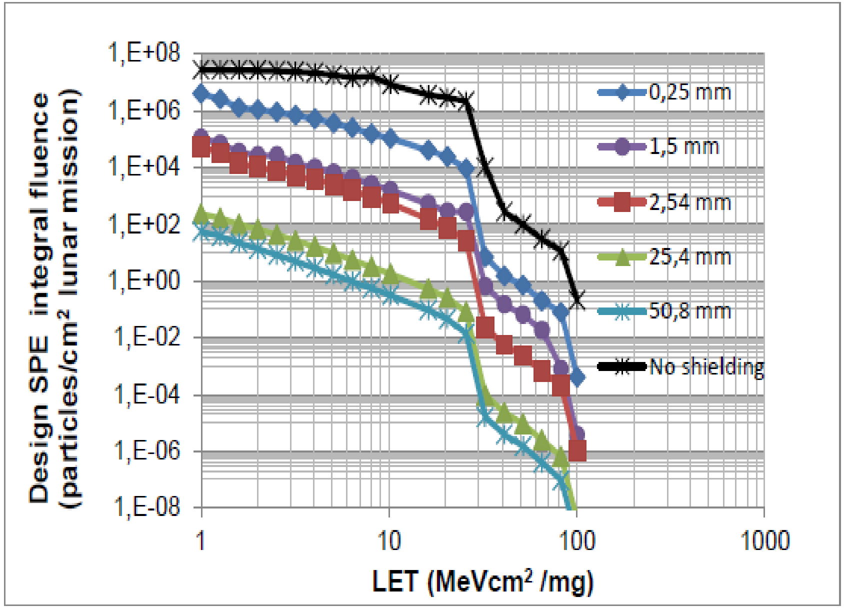
Particle spectra

Galactic cosmic rays



Solar particles



One particle is enough to cause a destructive effect if deposits enough charge in the device.

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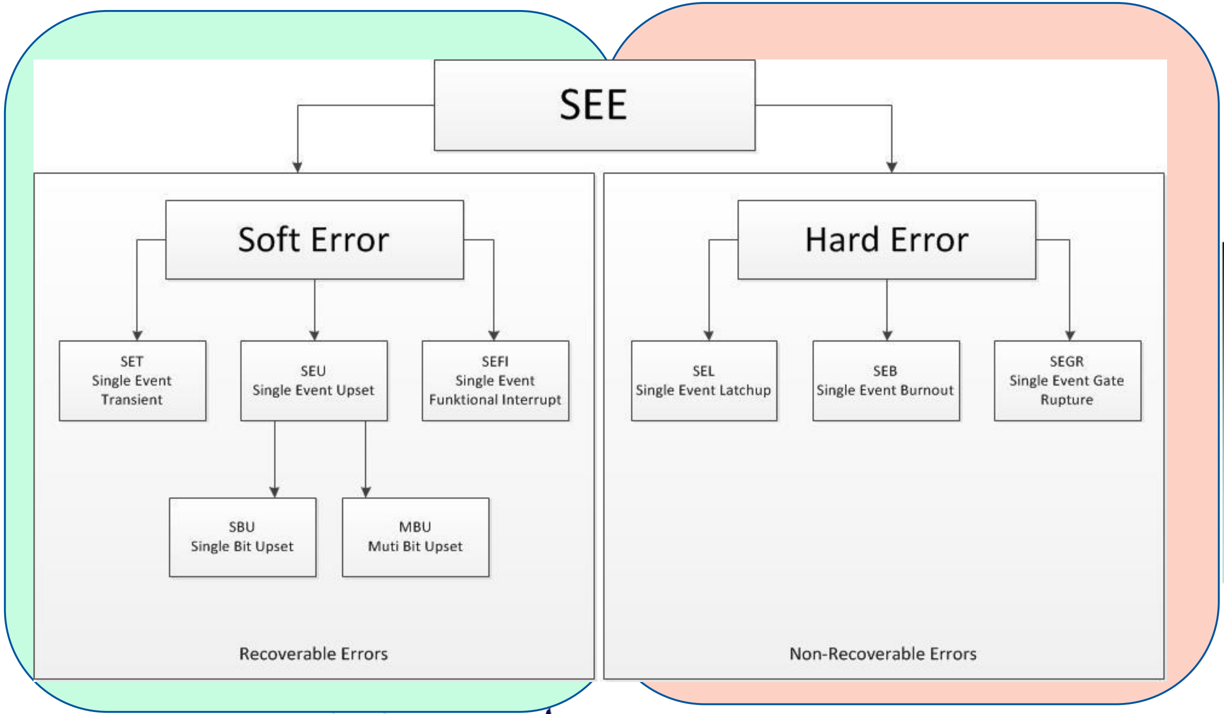
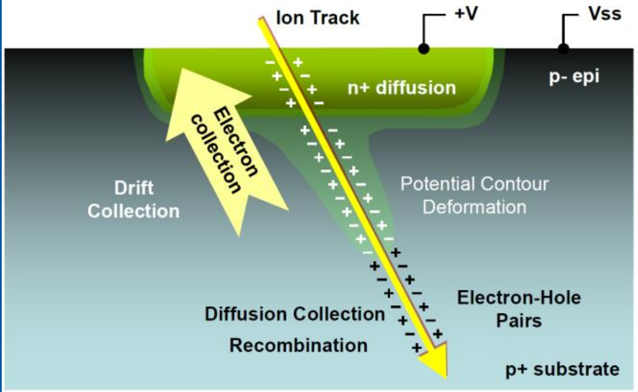
Single Event Effects





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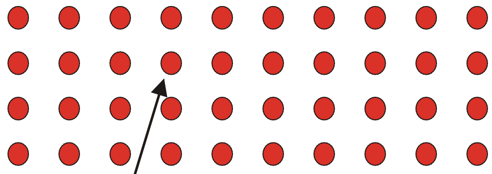
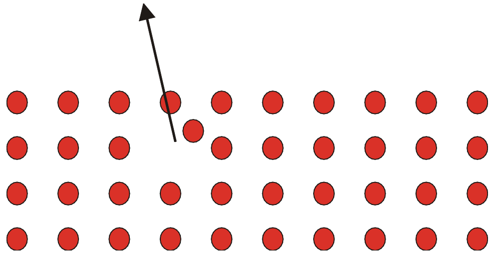
Total Ionising Dose

- Accumulated Radiation Damage: Total Dose Effects (TID Displacemt Damage)
  - Lattice Disturbances:

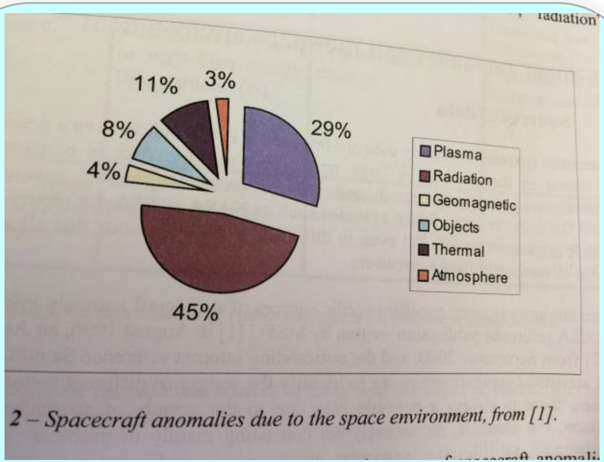


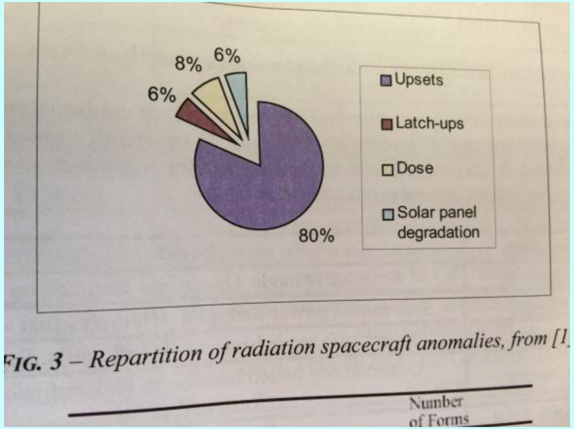


  - Charge Accumulation in Oxide Layers (left out here)

- For Low Eart Orbit Projects, TID effects are normally negligible.
- ISS Mission 1 year TID = 5 krad(Si) atthin shielding.
- Electric propulsion Jupiter missions Mrad at thin shielding.

Spacecraft anomalies





Anomalies represent a direct measurement of:

- Space environment modelling
- The adequacy of the spacecraft design

Reference: Spacecraft system failures and anomalies attributed to the natural space environment, NASA reference publication 1390, August 1996.

- 100 anomalies were studied and tracked to their root cause.

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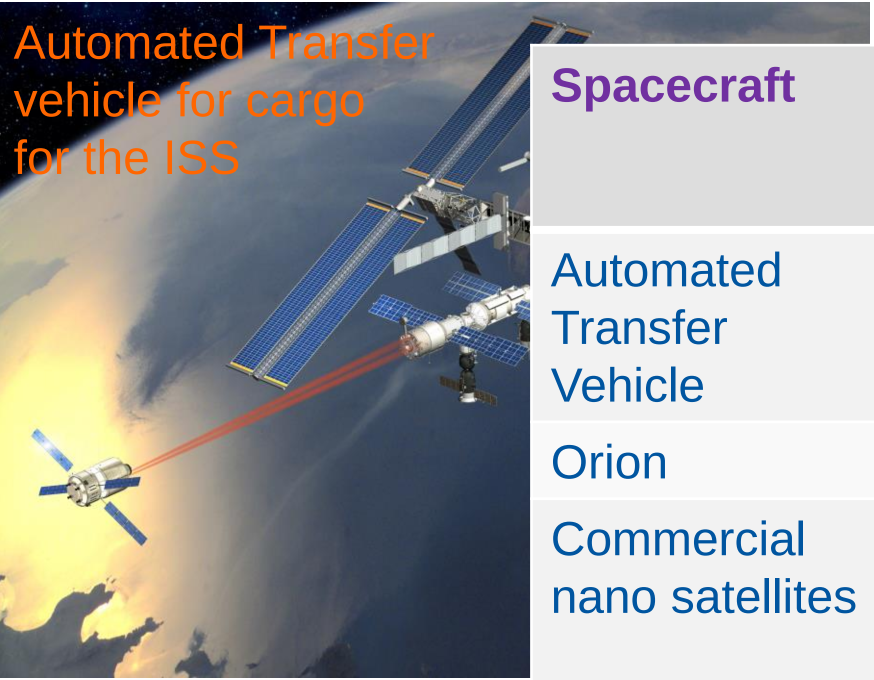
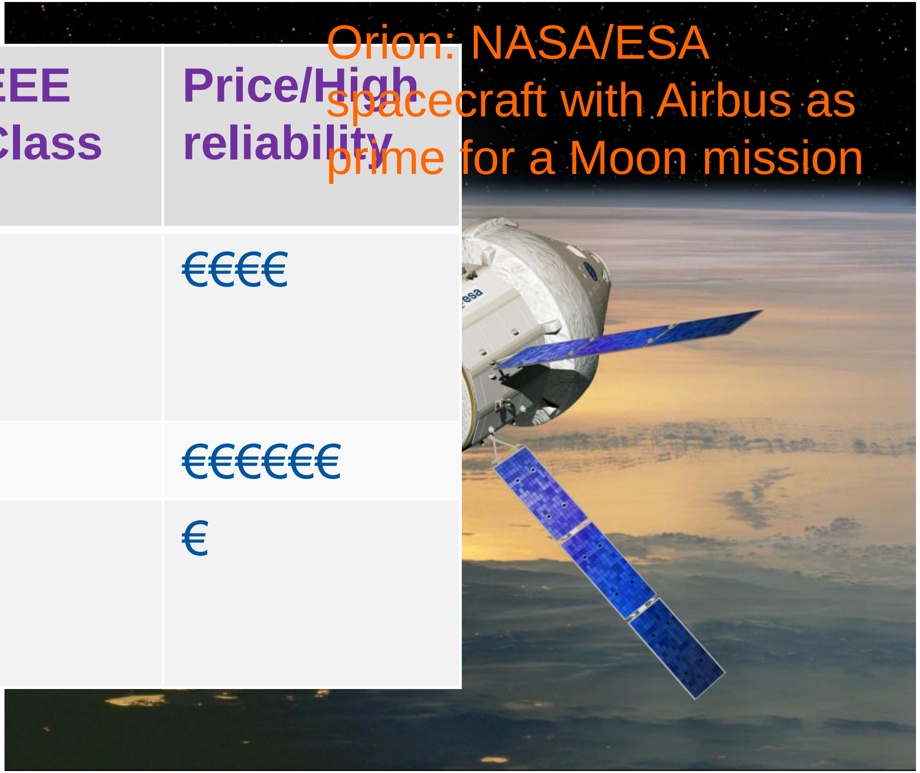
EEE parts: the good the bad and the ugly

Spacecraft Mission and EEE parts



Spacecraft	EEE Class	Price/High reliability
Automated Transfer Vehicle	2	€€€€
Orion	1	€€€€€€
Commercial nano satellites	3	€



Class 1 & 2 saga

- Supplier has to establish throughout the project a programe which ensures that project requirements are in compliance.
- Declared part list used as PDR and at CDR frozen
- Supplier organization needs to be compliant with the ECSS-M-ST-10.
- Component control plan
- Part Control Board
- EEE parts shall be chosen from preferred sources
- Radiation hardness shall be proven (TID, displacement damage, SEE effects)
- Radiation hardness assurance plan
- Radiation analysis
- Part approval (before CDR)
- Screening (initial source cap inspection, lot acceptance, final customer source inspection)
- Traceability during manufacturing and testing

Commercial off the shelf

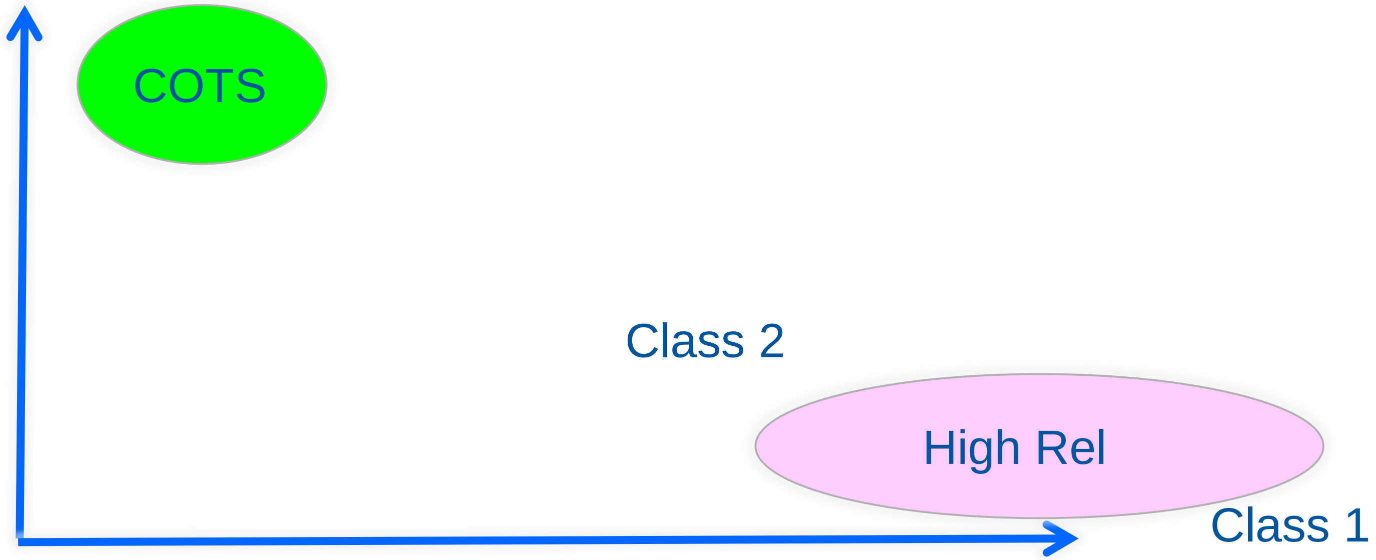
- You buy “as is”
- Manufacturer takes no liability for use in space
- There is no traceability possible
- No alerts wrt process change, foundry change
- No control whatsoever on the variability from lot to lot
- Parameters as in the data sheet

Fierce Competition: high rel. vs COTS

Availability

Functions

Performance



No specification for space

No radiation parameters

Lead Time Price

Heavily specified/tested

Government restrictions

Space 4.0 Era

Space 1 Astronomy time
Space 2 Apollo Missions

Space 3 International Space Station

Space 4 More players, no longer the preserve of governments of few nations, but commercial and private use

Time to market/mission: shorter!

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Commercial off the shelf qualification Project
(Airbus DS Bremen & ESA)

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International context PHY transceiver

- Time Triggered Ethernet (TTECH) technology gained worldwide momentum in the automotive and (aero)space industry. TTEthernet can be regarded as a successor of MIL-STD-1553 in certain critical applications, e.g. Human Spaceflight.

- NASA and Honeywell promote TTECH as baseline for the on board data bus system. Honeywell technology is rad-hard and ITAR protected.

- Large scale space projects deploying TTECH:

-NASA/ESA Orion manned mission to the Moon

-ESA next generation launcher Ariane 6

- Strategically important to safeguard and adapt commercial ITAR free technology with respect to one of the TTECH building blocks - PHY transceiver.

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Objectives

- Investigate the possibility to use commercial off the shelf Ethernet transceivers components for space use to circumvent the costly radiation-hardened development

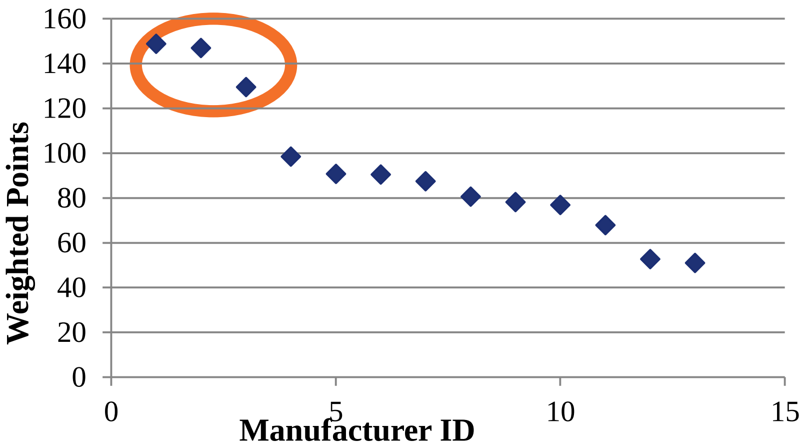
Ratio project budget rad hard development vs COTS characterization = 10.

- Perform a trade off and choose three-best transceiver manufacturers in a defined metric
- Run a full space qualification campaign on the parts
- Identify the parts/manufacturers with good/acceptable performance

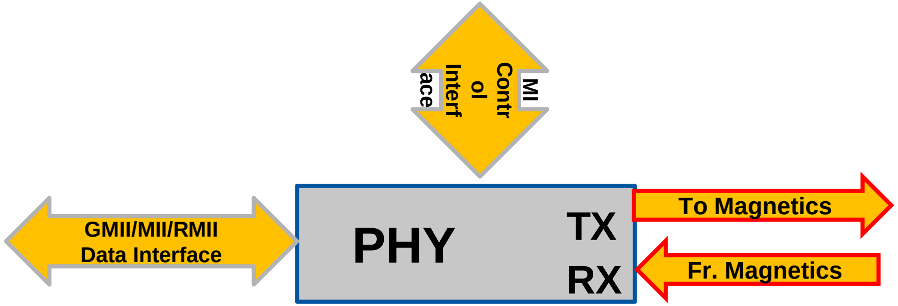
Ethernet PHY Transceivers Trade-off

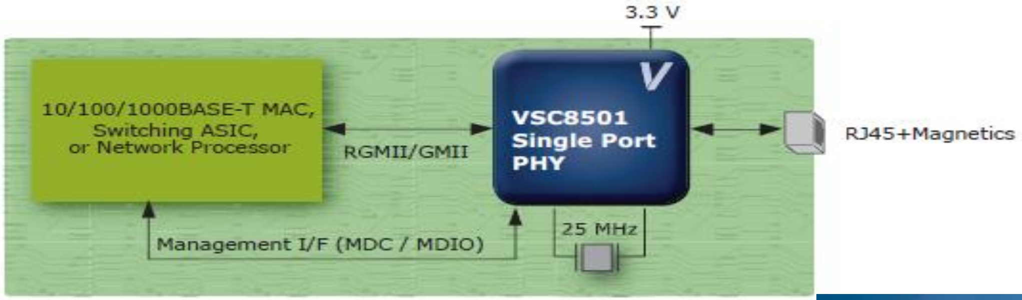
- Many selection criteria were taken into account and weighted according to their importance (e.g 1 for a hard requirement and 0.2 for softer design considerations)
- Functional: IEEE802.3 compliant, Interfaces(GMII, RGMII), Interrupt generation capabilities, autonegotiation
- Electrical: Copper based medium (10/100/1000MB/s), power consumption and management
- Mechanical (package soldering, temperature range)
- One single lot

Manufacturer Part	Weighted Points	No.
Vitesse/VSC8501	148,9	1
Marvell/88E1111	147	2
Lantiq/PEF7071	129,6	3
Avago/ET1011C	98,5	4
Micrel/KSZ9031MNX	90,8	5
Texas/DP83867	90,6	6
Micrel/KSZ9031RNX	87,6	7
Microchip/LAN8810	80,7	8
Texas/DP83865	78,2	9
Microchip/LAN8820	76,9	10
Broadcom/BCM5461	68	11
Realtek/RTL8211BG	52,8	12
Realtek/RTL8211DN	51,1	13



Ethernet PHY interfaces





Data Interface (xMII)

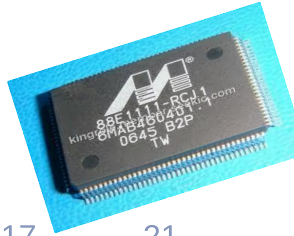
- Standard interface to connect a fast Ethernet media access control block to a PHY chip
- High speed parallel interface
- Used to send/receive data

Management Interface (MI)

- Serial slow interface
- Used to program/monitor the PHY
- Basic MI registers are defined in the standard

Choosen Transceivers

- Vitesse
- Marvell
- Lantiq



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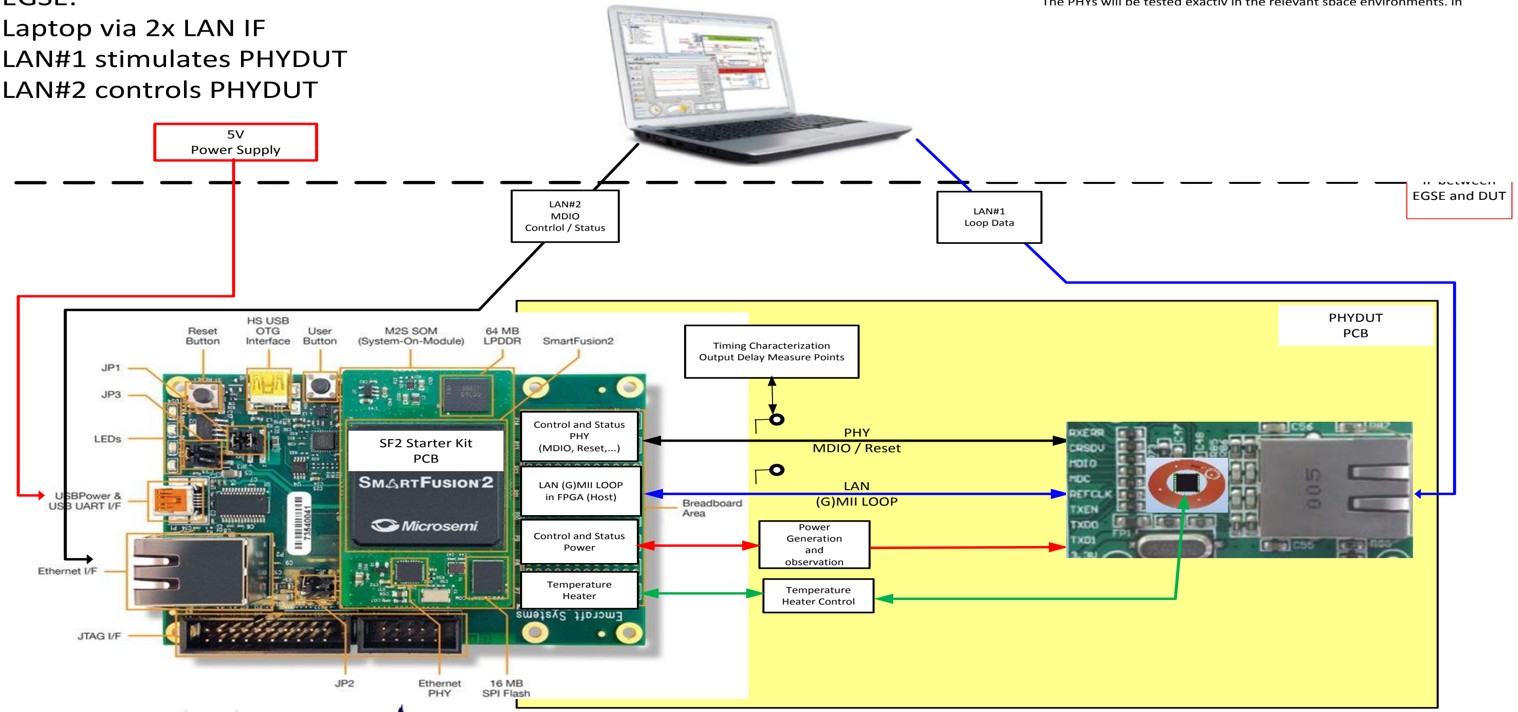
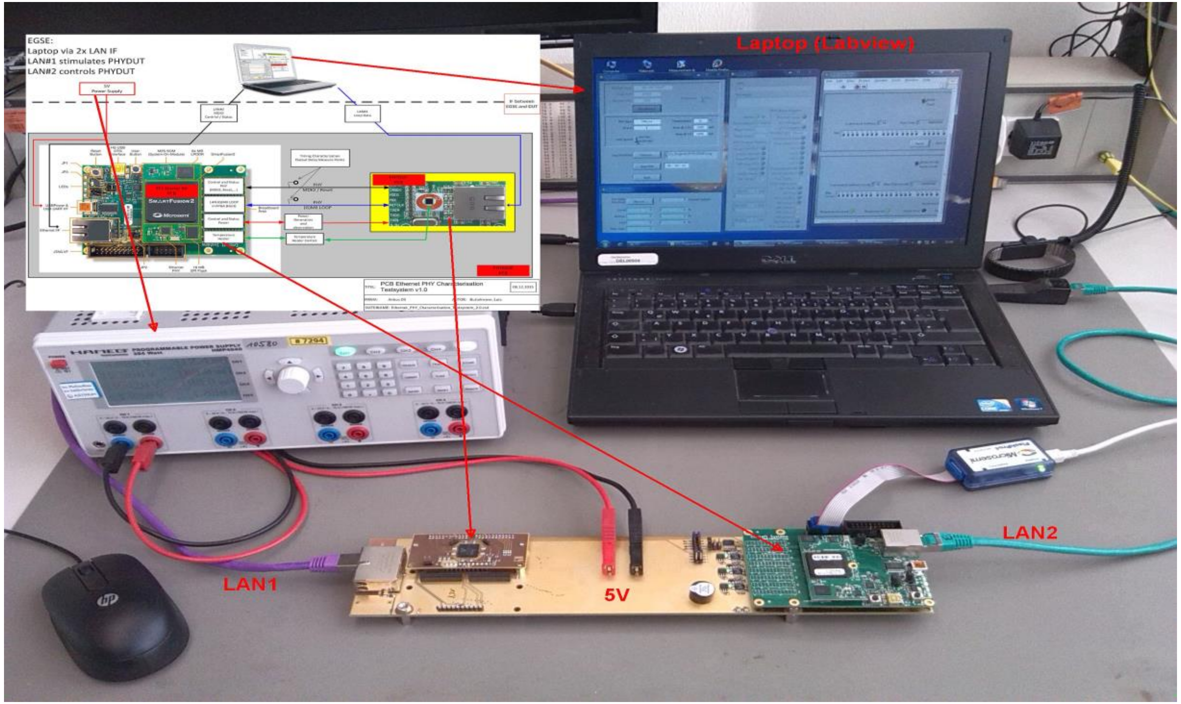
PHY testing concept

EGSE:
Laptop via 2x LAN IF
LAN#1 stimulates PHYDUT
LAN#2 controls PHYDUT

The PHYs will be tested exactly in the relevant space environments, in



PHY Testing Realisation



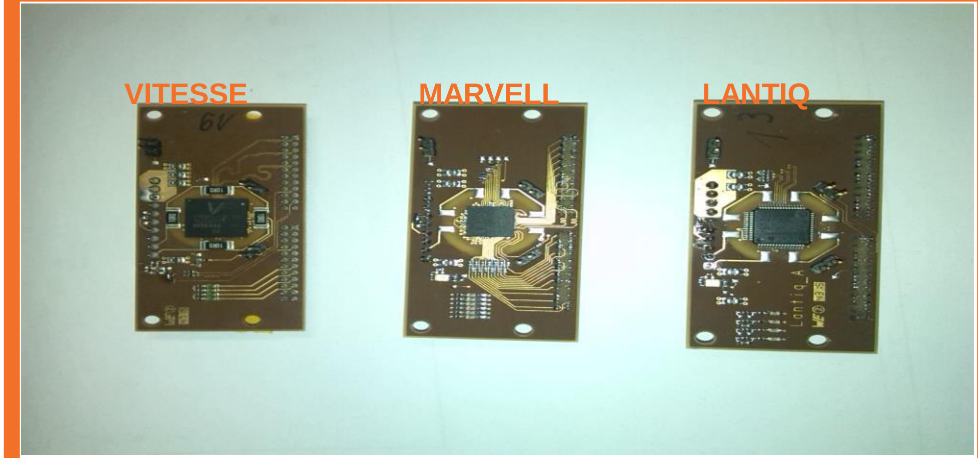
PHY DUT Control/Configuration

- Control and status registers for the EGSE implemented in the SF2 FPGA
- EGSE software can execute read/write accesses to internal PHY registers
- FPGA provides a register to reset PHY (after power on/after error)

PHY DUT (G)MII Loop

- No need for an Ethernet MAC controller
- Replaced by a simple loop inside FPGA

PCB Motherboards: PHY DUT



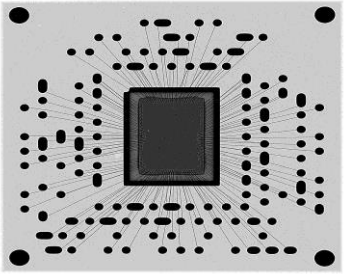
Packaging and Integration

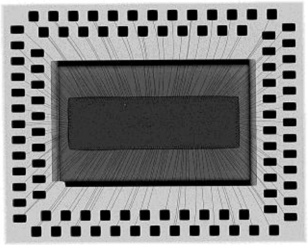
Transceivers have different packages, baseline is Quad Flat No-leads (QFN).

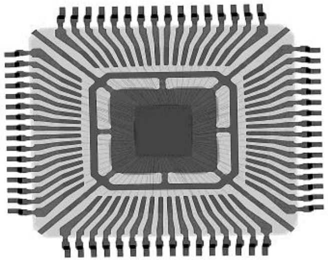
- 135 QFN, 96a QFN double row, 48QFN

QFN multi row is difficult to solder, but Airbus took th challenge.

A total of approx. 120 PHY DUT boards were manufactured, in two iterations.



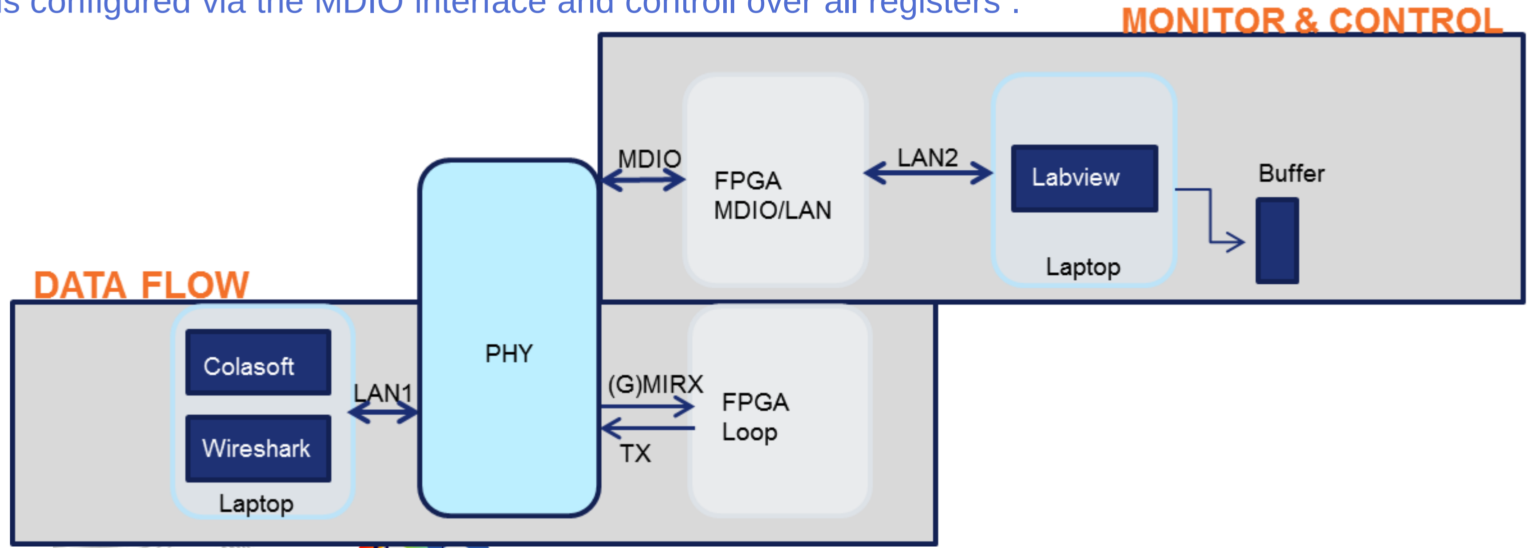




Data Acquisition

The Software architecture needed few layers in order to perform the communication with PHY DUTs:

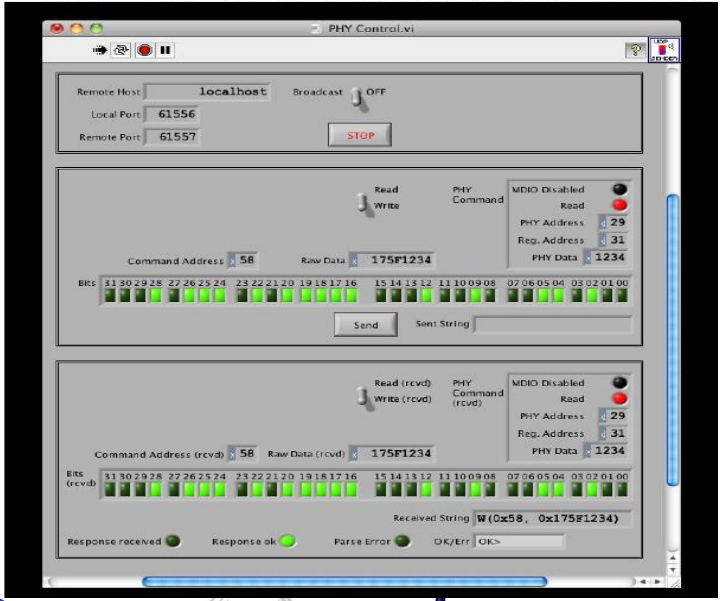
- **Colasoft** Network package builder sends custom network packets to PHYs.
- **Wireshark** reads/analyzes pcap logfiles containing network packets sent/reflected by PHY.
- PHY is configured via the MDIO interface and controll over all registers .

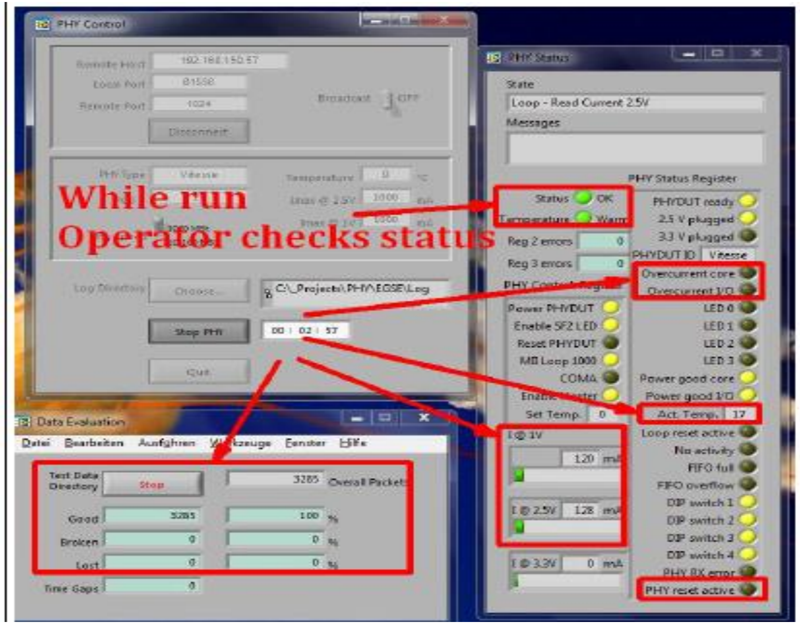


Data Acquisition

Software architecture

- Wireshark stores the captured packets locally on the laptop.
- Files are processed offline by the Labview Data Evaluation Application

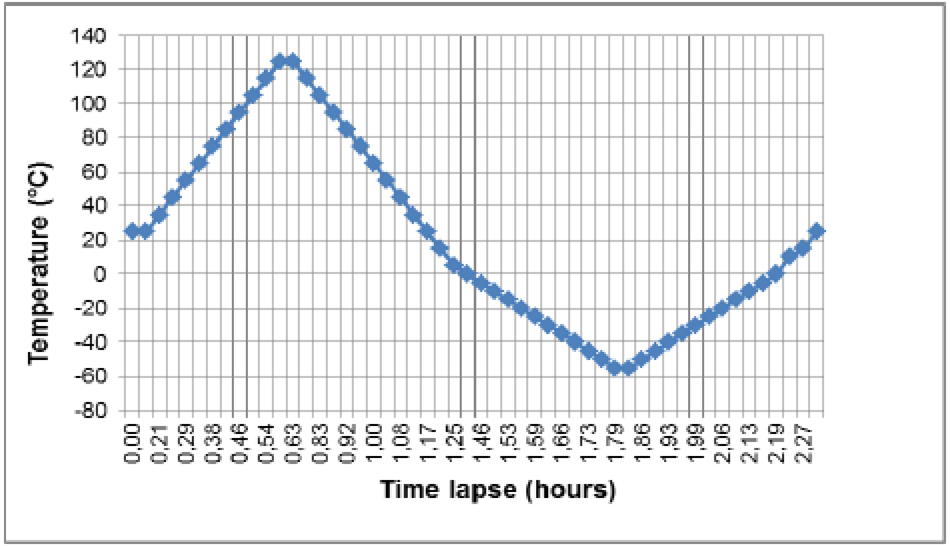




Environmental Tests

- Vacuum and thermal (T = 55°C) — OK
- Thermal testing: (100 cycles T = -55°C to +125°C) functional tests — NOK
- Outgassing test in accordance with ECSS-Q-70-02C — OK
- Offgassing test in accordance with ECSS-Q-70-29C — OK
- ESD Testing: 2000 V different repetition rates, functional — OK
- Life testing: 41 days T = 115°C functional test — OK
- **Radiation (Total Ionising Dose, Heavy Ions**, Protons)

Thermal testing



- 100 cycles T = -60°C 125°C
- Functional testing before and after
- Power consumption higher than at RT
- Devices functional apart from one Lantiq where the link could not be established after test

Offgassing

Test conditions ECSS-Q-ST-70-02C

- T = 50°C, N2 atmosphere
- Duration 72 hours
- Samples are subjected to air flow and offgased substances will be cooled down to 25°C and adsorbed on tubes
- Analysis of chromatograms
- Conduction: Bremen Environmental Institute

Parameters measured

- Carbon monoxide
- Volatile organic compounds
- Mass
- Projected Spacecraft concentration
- Individual Toxicity Value

CAS-Nr.	Substance	Test chamber concentration [µg/m³]	SMAC [µg/m³]	Mass [µg]	PSC [µg/m³]	T_{ind}
630-08-0	Carbon monoxide	49	63.000	0,0691	6,9E-04	1,1E-08
74-82-8	methane	n.d.	3.500.000	--	--	--
110-54-3	n-Hexane	44	176.000	0,0620	6,2E-04	3,5E-09
38640-62-9	Diisopropyl naphthaline	22	100	0,0310	3,1E-04	3,1E-06
84-69-5	Diisobutyl phthalate	7	100	0,0099	9,9E-05	9,9E-07
124-19-6	n-Nonanal	16	29.000	0,0226	2,3E-04	7,8E-09
64-19-7	Acetic acid	14	7.400	0,0197	2,0E-04	2,7E-08
541-05-9	D3 (Hexamethylcyclotrisiloxan)	64	90.000	0,0902	9,0E-04	1,0E-08
556-67-2	D4 (Octamethylcyclotetrasiloxan)	51	280.000	0,0113	1,1E-04	4,0E-10
various	Sum N-aromatic compound	8	100	0,0113	1,1E-04	1,1E-06

Results

- **T-value =** Sum (**T ind) < 0,5**
- All manufacturers compliant

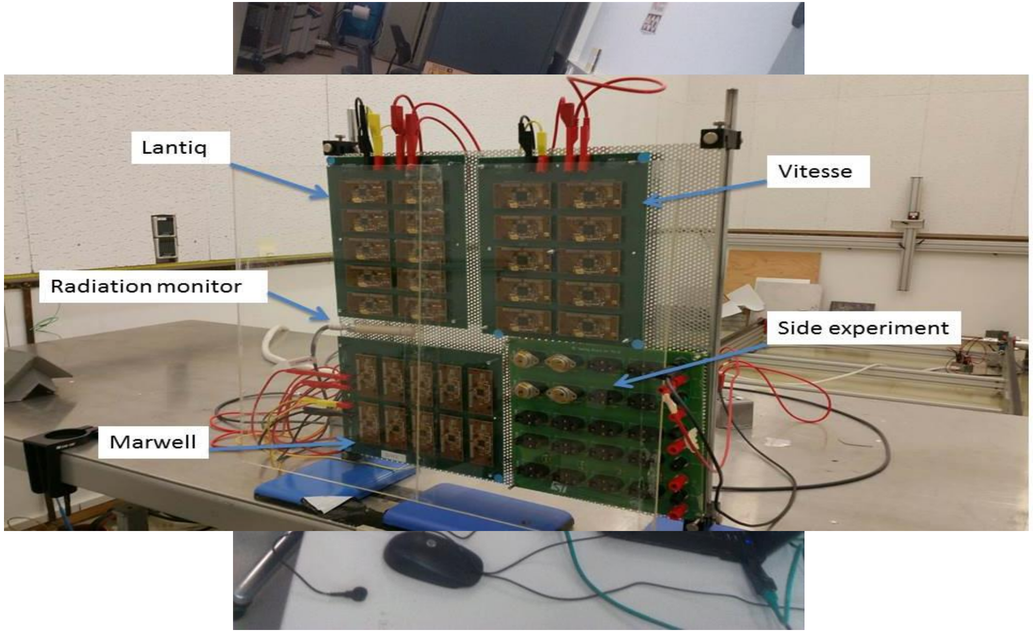
Total Ionising Dose

Test conditions

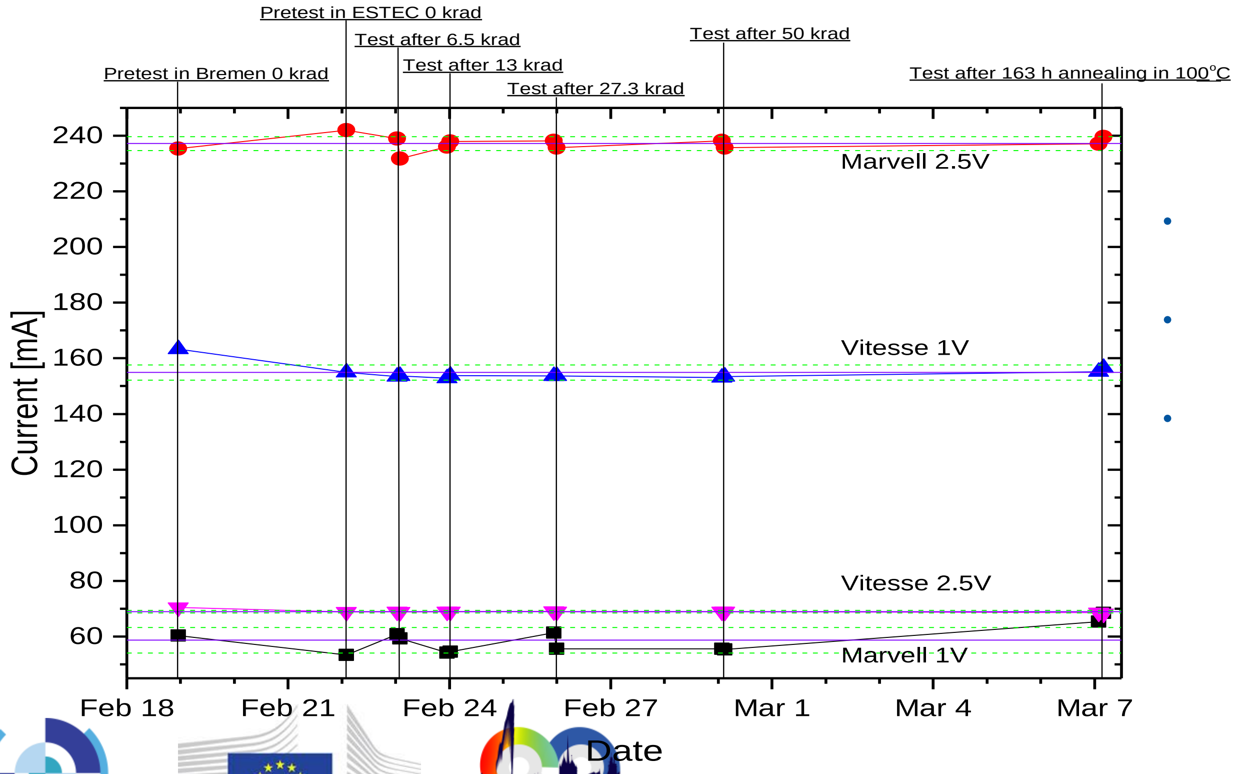
- 60Co source Activity(02.2016)= 47 Tbq
- Four irradiation steps: 6.5 krad, 13 krad, 27 krad, 50 krad
- Average dose rate 309.5 rad/h
- Data rate: 100MB/s, 1GB/s
- All samples biased
- Conduction: ESA/ESTEC 60Co laboratory
- ESCC 22900 Specification

Parameters measured

- PHY Functionality (packets sent/received)
- Current consumption
- RX Clock period for both datarates
- Data to Clock delay for both datarates
- Parameters measured after each irradiation step and after annealing

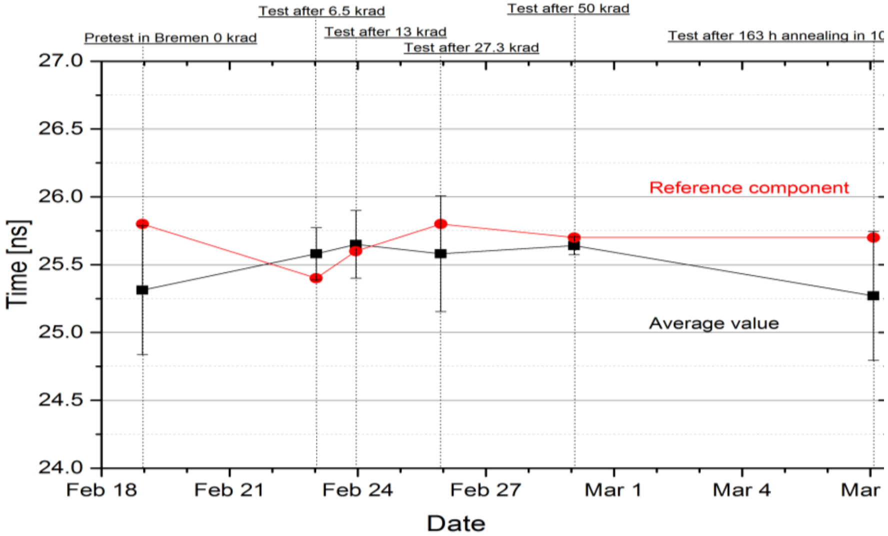


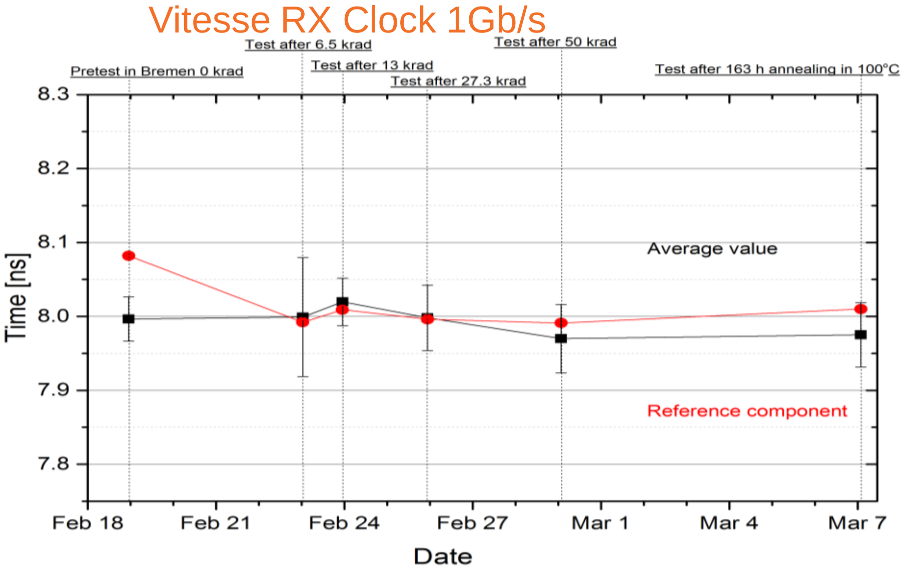
Total Ionising Dose: Key Results



- Each I/O current consumption was monitored: 1V and 2,5V.
- Average over 10 samples for each PHY.
- No radiation effect on the data.

Total Ionising Dose: Key Results: 50 krad(Si)





- No parametric degradation nor functional failures observed.
  - Missions: **Thick shielding ISS** Columbus 40 years. **Thin shielding**: Orion mission **1 year ISS** and 21 days **lunar fly by**. **Electric orbit**: thin shielding ray tracing 7 years.

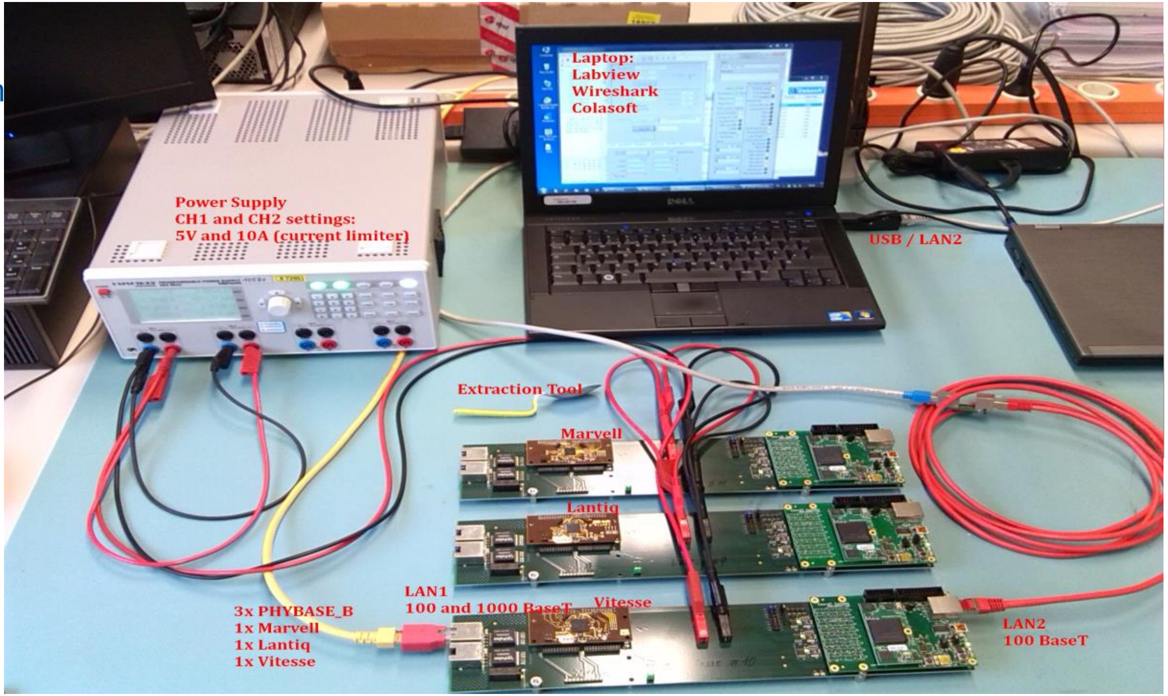
Single Event Effects Testing

Test conditions

- 9.3 MeV/u ion cocktail
- LET = 1.8, 10.2, 18.5, 32 and 60 MeVcm
- SEL T = 125°C SEU T = 25°C
- Fluence: 2E6-1E7 particles/cm^2
- Data rate: 100MB/s, 1Gb/s
- Conduction: RADEF K130 cyclotron

Parameters measured

- PHY Functionality (packets sent/received)
- Current consumption
- Number of errors: Data loss, Functional interrupts, Link loss, Latchup events
- Parameters monitored during each run and stored electronically



Single Event Upsets (SEU) Types

Data loss (DL) cross-section

$$\sigma_{DL} = \frac{\frac{number\ of\ lost\ data\ packages}{number\ of\ all\ data\ packages}}{FLUENCE}$$

Fluence is ions/cm^2 ;10% accuracy

Network package builder Colasoft used to send packets.

Format: UDP
Packet length: 64 byte

Wireshark software analyzed the sent back Packets.

Labview application counted the lost packets.

Functional interrupts

- Functional interrupt link lost (FILL)
PHY Status, Ethernet
Beam was turned off, PHY rebooted

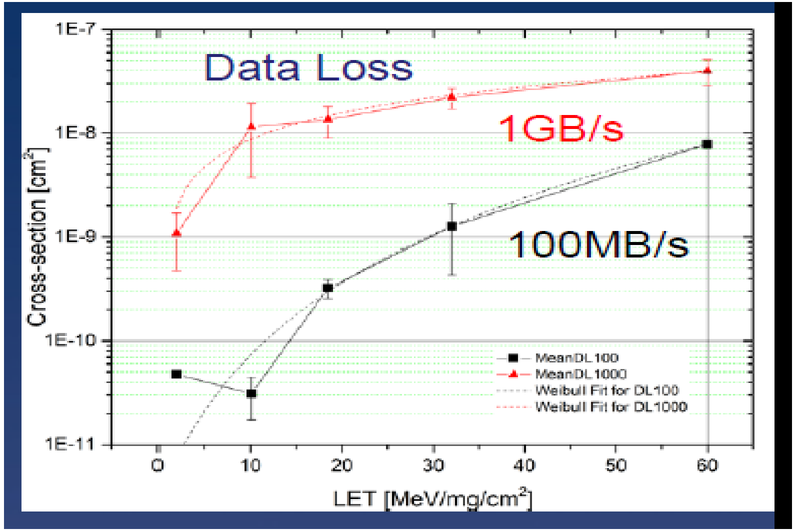
- Functional interrupt link not lost (FINL)
PHY Status, Ethernet
Beam was turned off, PHY rebooted

- Link lost and recovered (LLR)
PHY lost Ethernet connection but in few seconds recovers

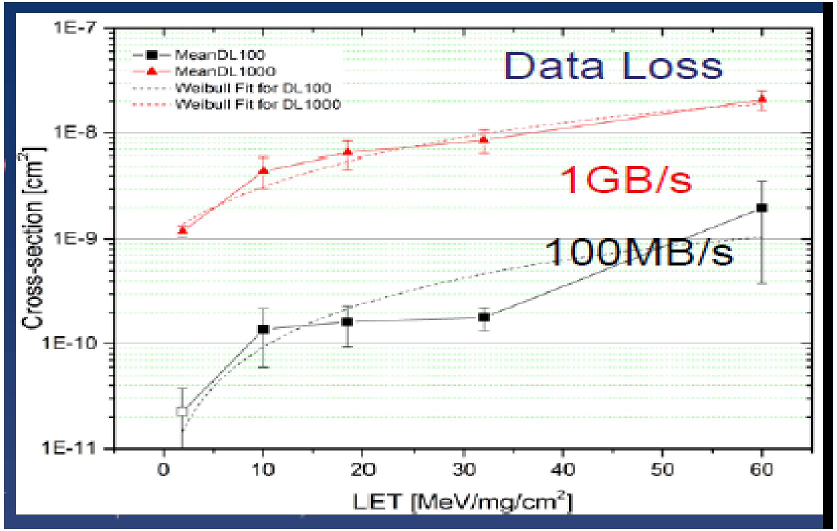
$$\sigma_{SEE} = \frac{number\ of\ errors}{FLUENCE}$$

Single Event Effects Results: Data Loss

Marvell



Vitesse

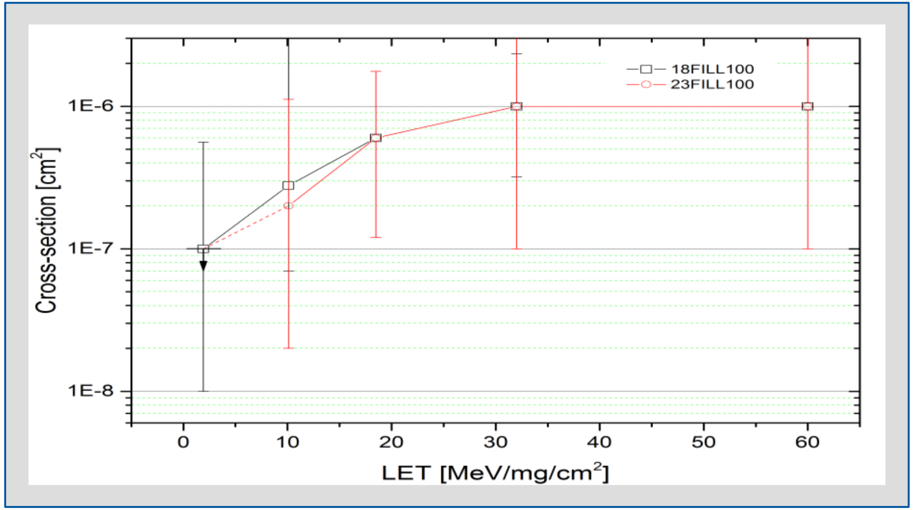


- Saturated cross-section 2E-8 2E-9 Vitesse. More susceptible in 1Gb/s than 100 MB/s.

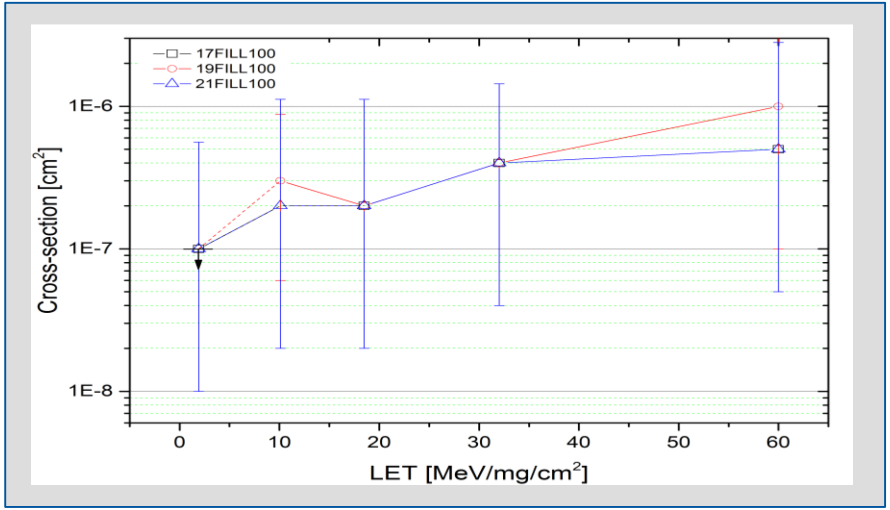
- Saturated cross-section 3E-8 7E-9 Marvell. More susceptible in 1Gb/s than 100 MB/s.

Single Event Effects Results: FILL

Marvell

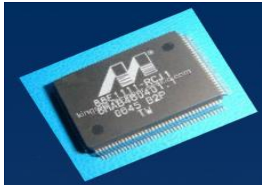


Vitesse



- Saturated cross-sections: 1E-6-3E-7 cm^2.

Characterisation Data Sheets



Characterisation Data sheet

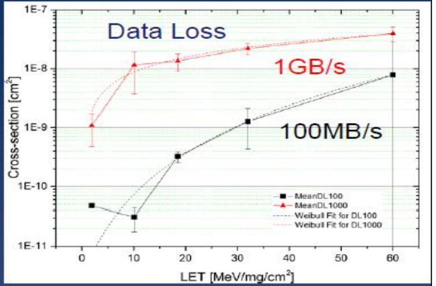
Marvel 88E111*

Lantiq failed the SEL test

Radiation Data

- Functional up to a TID = 50 krad(Si)
- No SEL effects up to an LET of 60 MeVcm²/mg
- SEU effects

-Data loss
-Functional interrupt with link loss
-Functional interrupt with no link loss
-Link loss and recovered
-Very moderate micro-latchup



Environmental Results

- Appropriate for use in vacuum
- Functional before and after thermal cycles between T = -55°C -125°C
- Functional during the ESD test (2000 V)
- Functional during 41 days life testing at T = 115°C
- Acceptance following the thermal vacuum outgasing procedure and limits of the ECSS-Q-ST-70-0C
- Toxicity value much smaller than the limit in accordance to the offgasing procedure/limits ECSS-Q-70-29C accepted

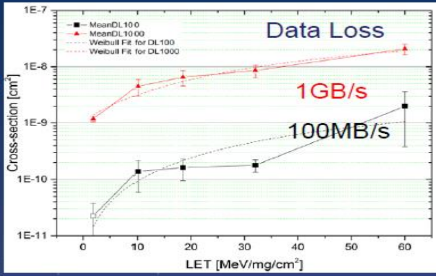
Characterisation Data sheet

Vitesse VSC8501*

Radiation Results

- Functional up to a total ionising dose of TID = 50 krad(Si)
- No SEL effects up to an LET of 60 MeVcm²/mg
- SEU effects

-Data loss
-Functional interrupt with link loss
-Functional interrupt with no link loss
-Link loss and recovered
-Very moderate micro-latchup



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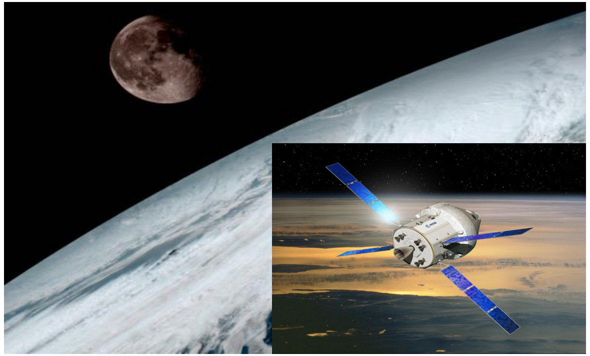
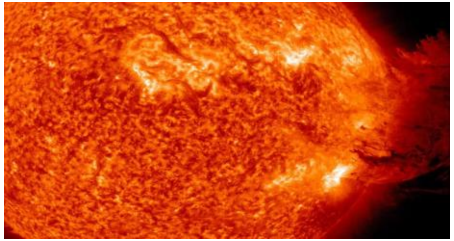
On Orbit Error Rates

International Space Station (ISS)

Lunar



Solar storm



Marvell

Single Event Effect	Radiation Environment		
	ISS nominal Error/day	Lunar nominal Error/day	Solar storm Error/day
FILL	3E-7	1E-5	8E-4
DL	9E-8	5E-6	2E-4

Vitesse

Single Event Effect	Radiation Environment		
	ISS nominal Error/day	Lunar nominal Error/day	Solar storm Error/day
FILL	1E-7	6E-6	3E-4
DL	7E-8	1E-6	5E-5

Conclusion and Outlook

- Sucessfully qualified two out of three transceivers for space deployment.
- Tranceivers are radiation tolerant: TID = 50 krad(Si) and SEL free to 60 MeV cm2/mg and could be deployed in a number of missions (not in manned missions).
- Mapped/quantified all classes of Single Event Effects: SEU, SEFI.
- Calculation of on-orbit rates showed for Vitesse very low SEU rates for an ISS mission 1E-7 per day and acceptable rates even in the solar storm scenario..

COTS qualification for space successful! Parts ready to go!

RADSAGA

European Commission

RADECS 2017
CERN, Geneva