Commercial-Of-The-Shelf (COTS) for LHC experiments

OUTLINE

What is a Commercial-Of-The-Shelf (COTS) component

COTS issues in LHC experiments

COTS Framework CERN proposal

RD49 outputs

COTS and technologies

Common CERN-LHC database

Radiation effects on electronics

Aging effects

- Total Ionising Dose (TID)
  - **charge hadrons (protons, pions)**
  - **electrons**
  - **gamma and X-rays**
- Displacement damage
  - **neutrons**
  - **protons, pions**
  - **electrons**

Transient effects

- Single Event Effects
  - **charge hadrons (protons, pions)**
  - **neutrons**
  - **heavy ions**

What is a COTS component

- It is a standard component which has by chance a good robustness against radiation effects
  - **Total dose, SEL latch-up and SEU**
  - **No qualification**
  - **No procurement guarantee, and uncertain traceability**
  - **AD9042 (ECAL ADC) is a “special” COTS**
- Definition of what is a component
  - **Integrated circuits on catalogue**
  - **El. cards, power supplies, full equipment**
- Radiation data on COTS: Space agencies
  - **Databases available in CNES, ESA-ESTEC, JPL-NASA, Goddard-NASA and CEA.**
  - **Very few available from LHC and HEP community**

COTS issues in LHC

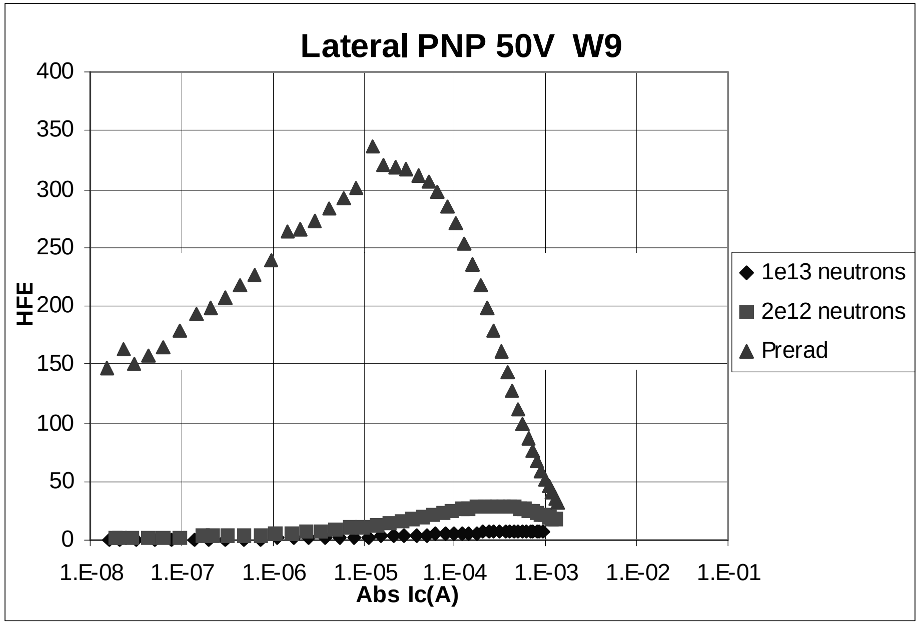
- COTS is not a solution, but it is a problem!
- Understand and manage radiation risks
- Very few radiation data available for neutrons
- Selection, testing, and qualification of COTS
  - **the main effort is for SEE testing (SEL, SEU)**
- Availability and validity of radiation data on COTS
- How LHC experiments will manage access to COTS
- Procurement strategies to be adopted

Risk of failure in COTS & radiation effects

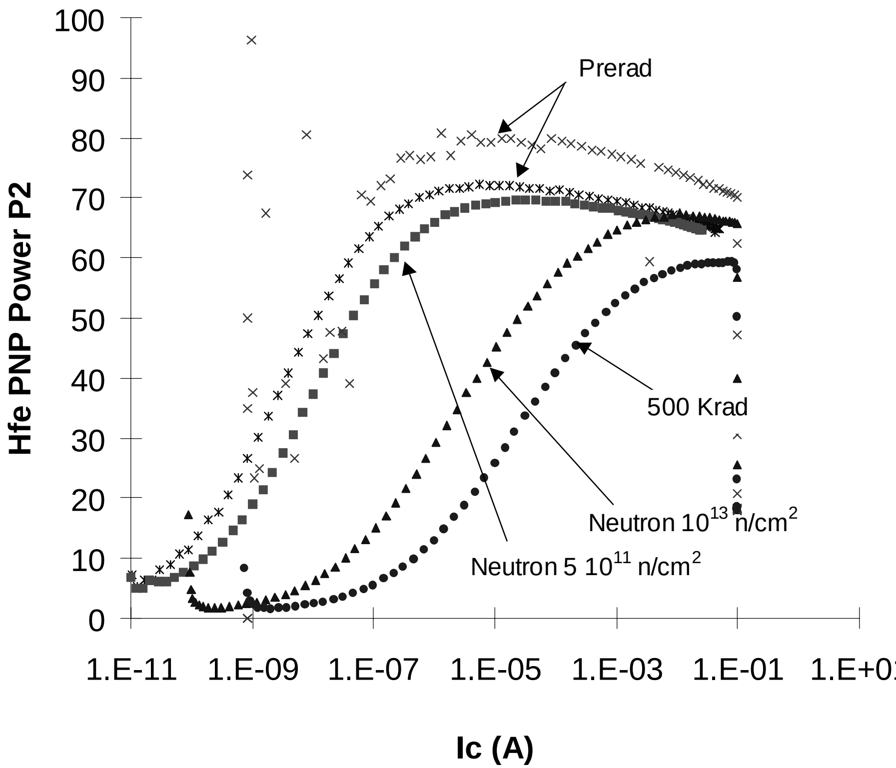
- Total dose: power increase, lost of functionality
  - **Modern digital CMOS COTS usually stands 10-20krad, but..exceptions**
  - **Power devices are generally soft: old technologies**
  - **Linear Bipolar ICs (Vreg, ampli , comparator)**
    - Affected by low dose rate effect
    - Presence of a lateral PNP is an important factor of risk
- Displacement damage: lost of functionality
  - **Risk above >10^{11}neutron/cm^{2}**
    - optocouplers
    - bipolar devices
- SEE effects:destruction of IC (SEL), lost of data
  - **the most important risk factor and the most difficult to manage**
    - SEL and SEU potentially threatening all CMOS circuits
    - Oxide breakdown (SEGR), Burnout (SEB) in high voltage power MOSFETs

Displacement damage & total dose ST Power bipolar technologies

Old technology with Lateral PNP



Modern technology power PNP



Understand and manage radiation risks

- Put the qualification effort where it is necessary
  - **Qualify COTS to SEL or SEU is an important effort**
  - **Effort should be focused on COTS with a recognised risk factor**
- Define local radiation environment
  - **radiation composition and radiation levels: total dose, hadrons**
- Identification of the severity of risk of COTS used
  - **type of the risk:SEE or total dose/displacement damage**
  - **component level: profit from an external expertise**
  - **system level: responsibility of the design team**
- Decide what to do:
  - **select & accept COTS with existing radiation data**
  - **test again previously selected COTS**
  - **select unknown COTS after testing them (valid radiation data)**

Severity of radiation risks

- Failure mode of the component
  - **degradation of performance: is it acceptable?**
  - **not functional: is it reparable?**
  - **destruction: is it protected and reparable? Compare to MTBF**
- Impact & propagation of the failure in the system
  - **Latch-up (SEL) : usually the most threatening risk**
    - but can be mitigated with appropriate latch-up protection circuits
  - **SEU impact on system (solution:mitigation: EDAC, redundancy)**
    - on ADC is acceptable
    - upset on data is acceptable
    - upsets in SRAM memory and FPGA used to store crucial information is an issue (in control system)
- No COTS solution:
  - **design a rad tolerant or rad hard ASIC: it is a major effort.**

NASA Analysis for SEE

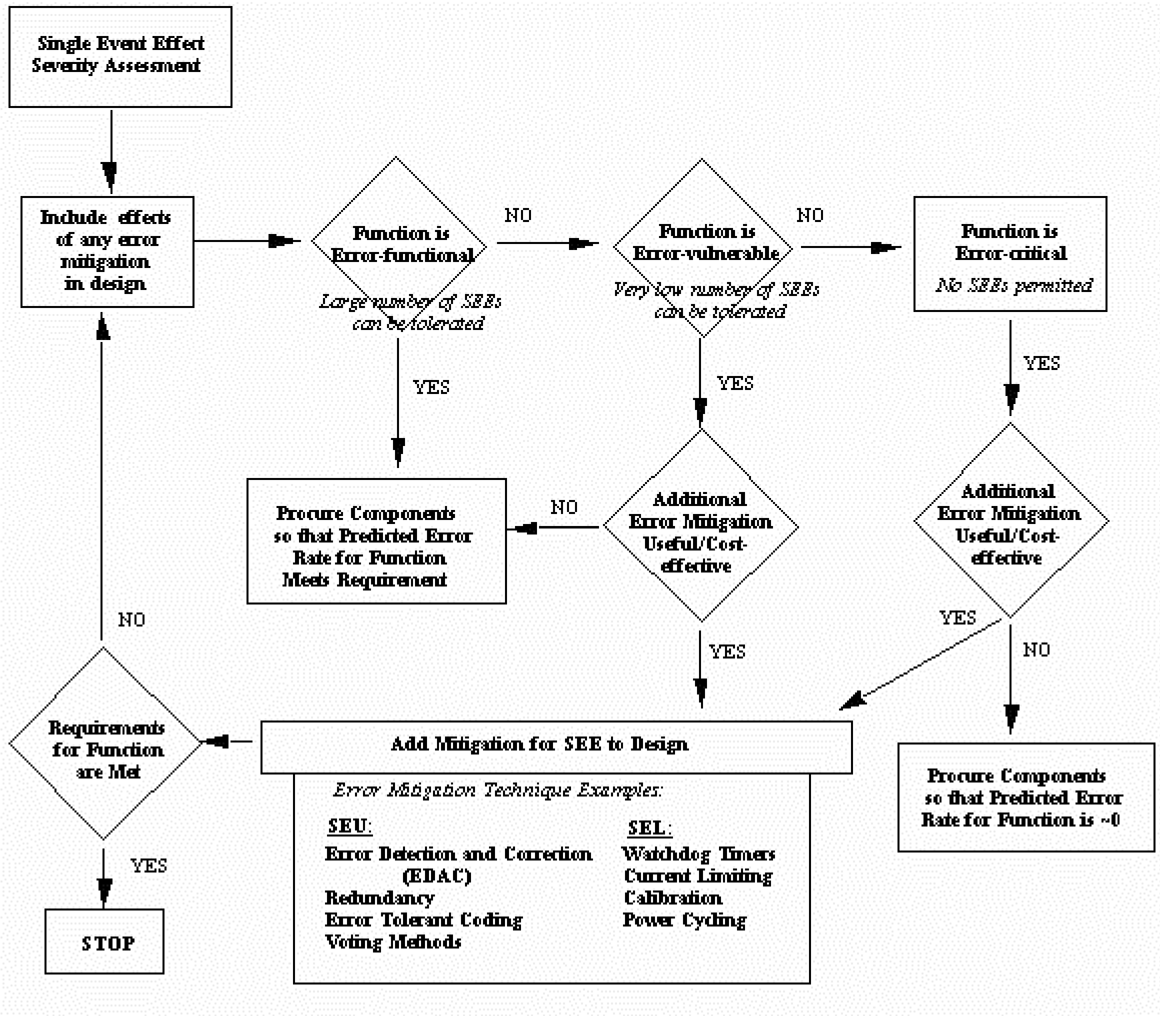


Figure 2.6: Single Event Effect Decision Tree

COTS selection and screening approach in Space Industry

- Radiation tolerance (SEE & total dose) of COTS checked
- COTS destroyed by radiation(SEL or total dose) are disqualified
- COTS with uncertain total dose tolerance are tested for lot qualification
- Complex ICs(microprocessors) showing SEU high sensitivity are disqualified
- Memory(SRAM and DRAM) showing SEU high sensitivity are used with bit error protection circuits.

Memory protection approaches Space community

- Memory with no protection
  - **1 or more SEU : potential severe failure**
- Memory with parity protection
  - **1 SEU: processor reset: 2 or more, potential severe failure**
- Error Detection and Correction(EDAC) protection
  - **1 SEU: negligible effect, 2 SEU, processor reset, 3 and > failure**
- SEU rate and MTBF of component (Mean Time Between Failure)

SEE risks with high energy neutrons

- High Energy neutrons: energy dependence
  - **So far, few data data available**
    - Hitachi SRAM, ATLAS G-link, FPGA
  - **SEE sensitivity increases with neutron energy**
    - at high energy equivalent to charged hadrons
  - **Latch-up (SEL) in CMOS circuits:**
    - Be careful with COTS with Th LET < 10-15 MeV $cm^2 mg^{-1}$.
- Thermal neutrons: $^{10}B(n,\alpha)^{7}Li$ reaction
  - **Small deposited energy**
    - Upsets have been observed on memories (Sandia NSS 97 paper)
    - No study available for latch-up: Th LET < 5 MeV $cm^2 mg^{-1}$.
  - **For LHC caverns, further study is necessary to evaluate the thermal neutron risk.**

Hitachi Neutron-induced upsets on SRAMs

Upset rate depends on neutron energy

SAAB - Xilinx
Neutron-induced upsets on SRAM-FPGA

- **XC4010E, XC4010XL tested with neutron: 11, 14, 100 MeV**
  - results is surprisingly good
  - better than SRAM : FPGA-SRAM have low pull up resistance of 5 kohms
  - No latch-up
  - for neutrons E < 11 MeV and <14 MeV: no upset up to a fluence of 10^{11} n/cm^2
  - for neutrons E< 100 MeV: 1 to 5 upsets for a fluence of 310^8 n/cm^2
- **Measured cross section**
  - 1 to 4 10^{-15} cm^2 /bit
  - Standard SRAM: 10^{-12} 10^{-14} cm^2 /bit
- **Is susceptible to total dose**

FPGA: SEU measurement Lookheed Martin Xilinx

XQR4013-36-62 XL:advanced FPGA in 0.35 um CMOS on EPI, 30K-130K gates
much higher susceptibility:Th LET< 10 MeVcm^2/mg, σ=$10^{-7}$$cm^2$/bit with ions
very expensive...

Considerations on COTS qualification procedures

- Testing of all components is not possible
  - **minimize number of components with radiation risks: standardisation**
  - **to many ICs components, less at system level**
- Determine local radiation environment ⇒ criteria
  - **define appropriate radiation tests**
- Determine component susceptibility
  - **function, technology, known radiation data: SEE, total dose**
- Define severity of radiation effects at system level
  - **Consequences of latch-up, upset and total dose**
  - **appropriate mitigation technique**
- Lot qualification? Only for crucial components?
  - **procurement issues ⇒ virtual customer**

COTS qualification and System level

- Total dose effects
  - **standard qualification protocols introduce hidden safety factors**
    - transistor level: worst case bias (and dose rate conditions applied)
    - component level: mixed worst case and operating bias conditions
    - in system: normal operating conditions.
  - **better radiation test results at system level**
- SEE effects
  - **Same trend, if appropriate protection and correction circuits used**
- Qualification of systems is attractive
  - **less work, testing in full operational conditions**
  - **accept to take risks on components with unknown radiation response**
  - **SEE testing : protons and neutrons**

RD49 activities in COTS

- Establish contacts with Space agencies
- Meetings where COTS issues are discussed
- Crucial list of COTS for LHC experiments
- Investigate SEE risks: SEL and upset rate
- Development of a rad tolerant voltage regulator
- Learn radiation risks with technology trends

List of crucial COTS for LHC and comments

- Standard digital ICs, in majority CMOS
  - **In principle for in-cavern electronics, total dose qualification is not required for levels < 5krad for parts fabricated in modern technology. Latch-up risk should be clarified in caverns.**
- Voltage regulator
  - **The main risk factor is the use of lateral PNP device, Rad-tol voltage regulator in development with ST compatible high neutron fluence.**
- FPGA
  - **robustness for total dose 3krad to 300 krad**
  - **susceptibility to upset, even for “rad hard” version in peripheral circuits; but some good results with neutrons.**
- SRAM
  - **total dose: 5 to 50 krad, large variability between suppliers and lots**
  - **Upset is the main risk, to be checked for caverns.**

.. *COTS list*

- ADC and DAC
- Optocoupler
  - **sensitivity to displacement damage**
- DC-DC converter
- Optical link system
- fieldbus
- Signal processors
- Microprocessors
- +...

SEE risks: SEL in standard CMOS upset rates in CMS

- Latch-up SEL measurement of ALICE 128 in 1.2 um process
  - **ASIC designed without special radiation tolerant precaution**
  - **test with heavy ions 8 to 60 MeV cm^2 mg^{-1}**
  - **Measured threshold LET of 8 MeV cm^2 mg^{-1}, with a high cross section 5 10^{-3}**
- SEU study in quarter micron CMOS
  - **in collaboration with CMS, valid for ATLAS**
  - **development of a method of prediction of the SEU rate**
    - definition of the sensitive volume : sensitive surface and sensitive depth
    - determination of the critical energy: from LET-cross section measured with ions
    - simulation of the radiation environment: determine probabilities of energy depositions
    - numerical integration of the probabilities of energy depositions above the critical energy

Comparison of parameters with SEU data on commercial SRAMs

			Sensitive Area		Proton X-sections				
Part	Cells		per cell (um2)		calculated	measured	difference		SV size
2901B	80		3750.0		4.858E-10	8.47E-10	**0.57**		2x2x2
									2x2x2
HM6116	16384		402.8		9.179E-09	4.59E-08	**0.20**		2x2x2
HM6516	16384		183.1		1.452E-09	2.46E-09	**0.59**		2x2x2
62256R	262144		244.1		9.523E-08	1.47E-07	**0.65**		2x2x2
OW_62256	262144		164.0		3.354E-08	8.7E-08	**0.39**		2x2x2
62832H	262144		38.1		8.937E-09	2.89E-08	**0.31**		2x2x2
HM_65656	262144		42.0		3.31E-08	2.98E-08	**1.11**		2x2x2
SMJ44100	4194304		47.7		7.432E-07	7.00E-07	**1.06**		2x2x2
MT4C4001	4194304		31.0		3.567E-07	2.94E-07	**1.21**		2x2x2
MT4C1004C	4194304		31.0		3.87E-07	3.94E-07	**0.98**		2x2x2
KM41C4000Z-8	4194304		31.0		2.944E-07	3.27E-07	**0.90**		2x2x2
TC514100Z-10	4194304		50.1		8.08E-07	1.00E-06	**0.81**		2x2x2
MB814100_10PSZ	4194304		76.3		1.181E-06	6.9E-07	**1.71**		2x2x2
HYB514100J-10	4194304		50.1		1.074E-06	1.46E-06	**0.74**		2x2x2
D424100V-80	4194304		35.8		1.028E-06	1.76E-06	**0.58**		2x2x2
01G9274	4194304		2.3		2.247E-09	4.19E-09	**0.54**		1x1x1
LUNA_C	16777216		0.9		1.784E-08	2.12E-08	**0.84**		1x1x1
IBM_16MEG	16777216		0.8		9.537E-09	2.12E-08	**0.45**		1x1x1
IBM64k	65536		12		2.059E-09	5.61E-09	**0.37**		1x1x1

Estimated upset rate in CMS tracker for sub micron technology

- Parameters for the test case
  - **sensitive volume:1μm**
  - **critical energy:1 MeV**
  - **5 10^7 s =10 years equivalent LHC**
  - **Simulation of the CMS tracker including all charge hadrons and neutrons E>20 MeV**
- Estimated SEU rate (calo / caverns: suppose same particle composition)

from beam line	Flux/s	upset rate/s	upset/bit for 10 years
4.3 cm	4.9 10^7	8.3$10^{-7}$ upset/bit	41 upsets/bit
32 cm	1.4 10^6	2.4$10^{-8}$	1.2
115 cm	4.7 10^4	8$10^{-10}$	0.056
Calorimeter	10^4	1.7$10^{-10}$	0.012
Cavern	2$10^3$	3.4$10^{-11}$	0.0024

SEU- induced thermal neutrons

- Low energy neutrons have not been considered
- SEU Susceptibility to thermal neutrons
  - **Depends strongly of the threshold LET**
  - **Select SRAM parts with a high threshold LET**
- Expectations based on Sandia results
  - **cavern : 10^{11} n cm^2/s maximum**
  - **upsets rate: 210^{-12} to 310^{-11} /bit s (variability with SRAM)**

COTS Framework CERN proposal

- Proposed objectives of the project
  - **Advising role**
    - COTS selection and procurement
    - COTS radiation database
  - **Coordination role**
    - indispensable COTS for LHC experiments.
    - sharing COTS between experiment
    - closed contact with Agencies
    - help for radiation test facilities, especially SEE
  - **Hardening assistance role**
    - participate in reviews of LHC electronics systems
    - co-ordinate custom development when necessary (no identified COTS)

Resources and Tasks

- One project Coordinator (expert in radiation effects)
  - **F. Faccio MIC-EP**
- One link person for each LHC experiments and machine?
- One external expert
  - **Len Adams/ Brunel, (30 years experience at ESA)**
- Tasks
  - **improve co-ordination of COTS qualification efforts**
  - **collect results and make them available through a centralised database**
  - **Set up and support qualification protocols & procurement strategies to facilitate selection of COTS and minimise risks**

SUMMARY

- COTS issues for LHC
  - **understand and manage radiation risks, component and system levels**
  - **very few radiation data available for fast neutrons**
  - **and even less for thermal neutrons**
  - **testing effort : standardisation of indispensable COTS**
  - **global procurement strategy not defined**
- SEL in components is a threat in LHC
  - **all standard CMOS are susceptible**
  - **define a criteria of acceptance**
  - **adopt mitigation techniques**
- SEU
  - **consequences in control system should be clarified**
  - **First estimate of upsets rate give a first picture of the risk**