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ASIC Radiation Testing Methodology and Techniques (AMICSA 2012)

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Outline

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1. Introduction.
2. Radiation Hardness Assurance and Radiation Test Guidelines.
3. TID testing.
4. Relevant SEE for ASICS and testing tips.
5. ESA Irradiation Test Facilities.
6. Conclusion.

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Introduction

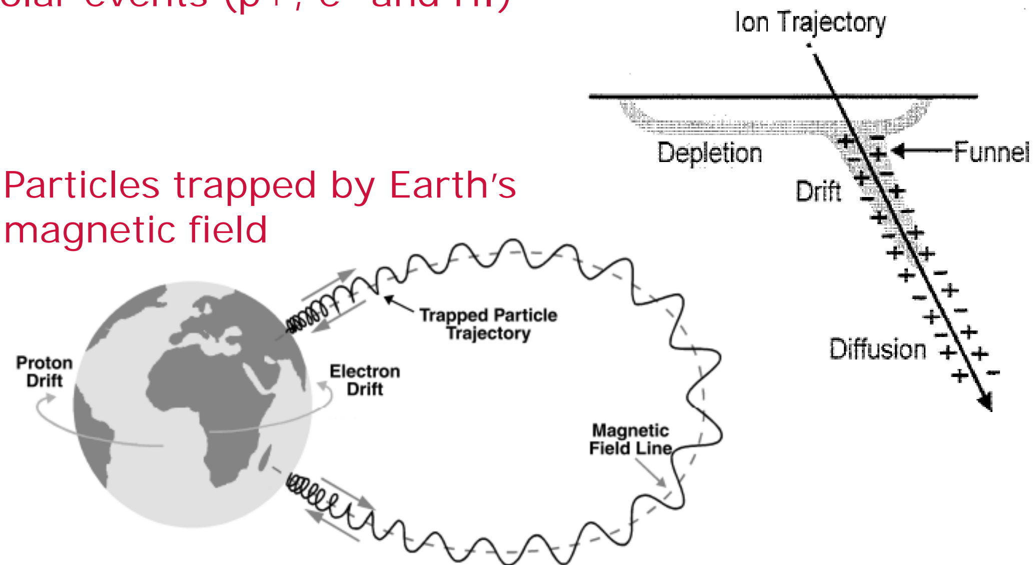
- Spacecraft electronics are exposed to a wide spectrum of charged particles (**electrons, protons and heavy ions**) that deposit charge on devices through ionization. **The amount and nature of the radiation received depends on the orbit, magnetic activity, mission lifetime and shielding.**
- Space Radiation Environment affects spacecraft electronics inducing parametric drifts due to cumulated dose (TID and TNID) and single event effects (SEE) due to single energetic particles. **Radiation effects depend on the targeted device structure, functionality, biasing conditions and temperature.**
- **Spacecraft electronics sensitivity to radiation must be assessed**.
- Mixed Signal ASICS complexity make them potentially sensitive to all known radiation effects

GCRs

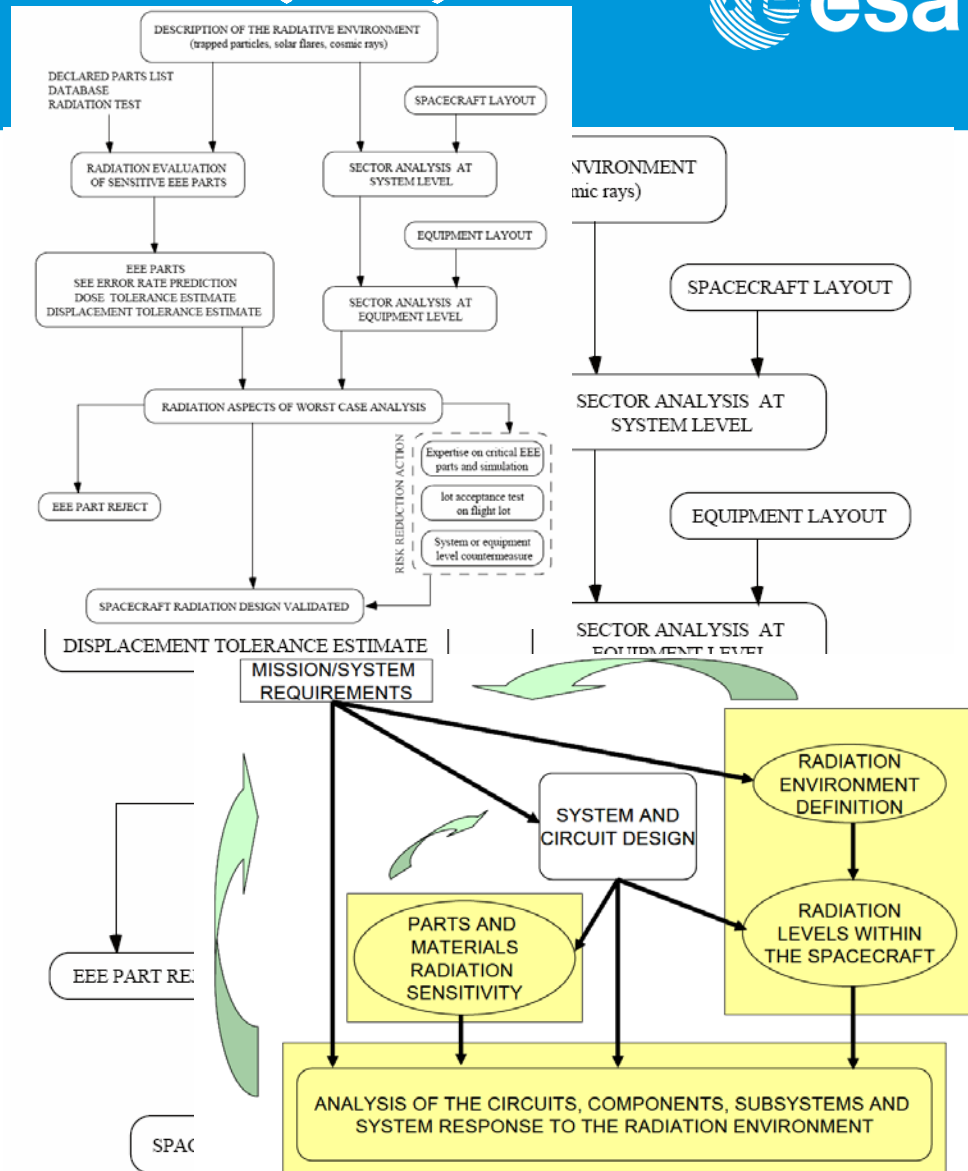
(p+ and high energy HI)

Solar events (p+, e- and HI)

Particles trapped by Earth's magnetic field



Radiation Hardness Assurance (RHA) & Test Guidelines.



RHA documents:

- **ECSS-Q-ST-60-15**. Space Product Radiation Hardness Assurance (publication expected by end of 2012 and it will be included in the list of ESA approved standards, the final draft as agreed is available on request).
- ESSB-ST-Q-001. ESA internal RHA.
- **ECSS-E-ST-10-04**. Space engineering Space environment.
- **ECSS-E-ST-10-12**. Space engineering Evaluation of radiation effects

Test Guidelines:

- **ESCC22900**. ESCC Basic Specification: Total Dose Steady State Irradiation Test Method.
- MIL-STD-883C method 1019.X Ionizing Radiation (Total Dose) Test procedure.
- **ESCC25100**. ESCC Basic Specification: Single Event Effect Test Method and Guidelines.
- JEDEC standard JESD57. Test procedure for the management of single-event effects in semiconductor devices from heavy ion irradiation.
- MIL-STD-750F method 1080 MIL-STD: Single Event Burnout and Single Event Gate Rupture Testing.
- MIL-HDBK-814.Ionizing Dose and Neutron Hardness Assurance Guidelines for Microcircuits and Semiconductor Devices.

Refer to download https://spacecomponents.org/ download http://www.ecss.nl to download European standards.

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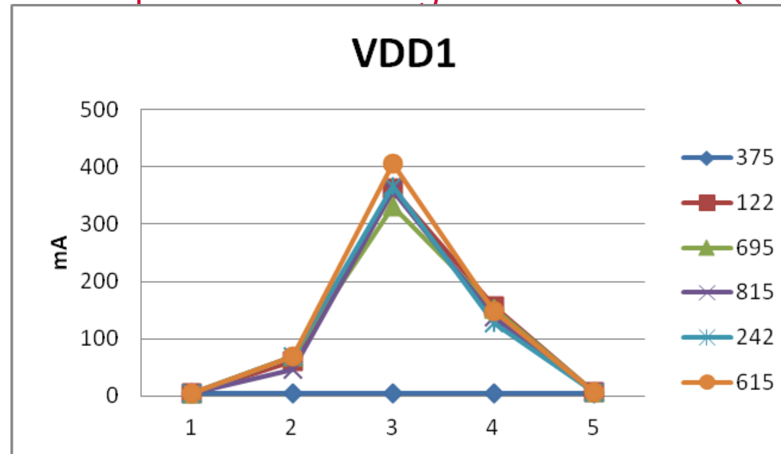
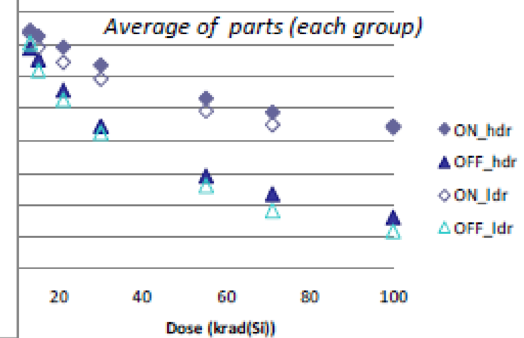
Mixed-Signal ASIC TID testing tips

1. Test relevant electrical parameters of the DUT with adequate sampling size (at least 3 devices for each biasing condition) and accuracy.
2. Bi-CMOS ASICS may be sensitive to ELDRS and TNID.
3. CMOS ASICS can be tested at HDR and are in general more sensitive in ON conditions.
4. Rebound effect may appear after annealing at HDR or even at LDR dose rate.

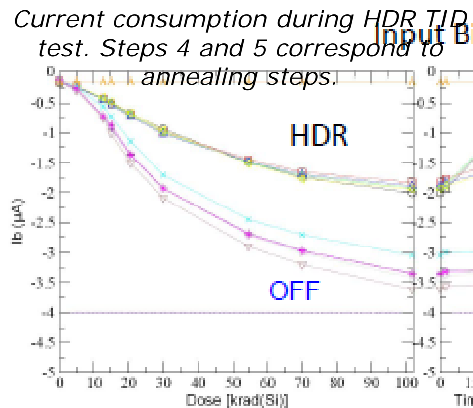
CMOS ASIC TID Test

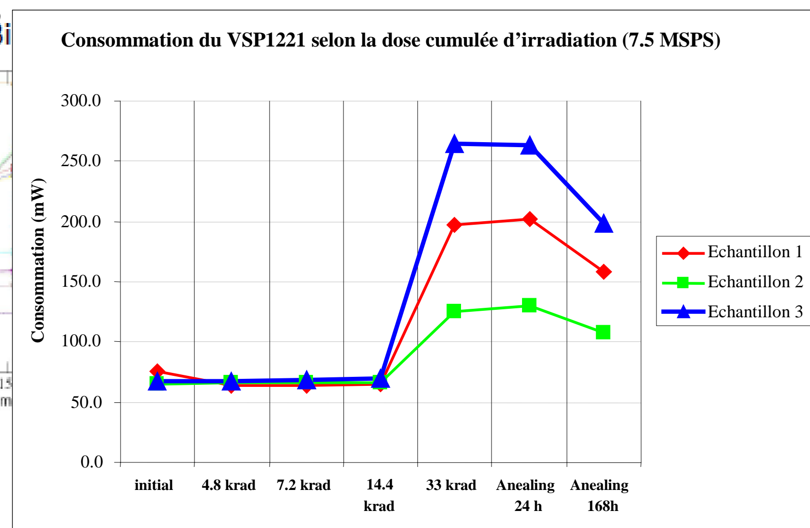
Bipolar Linear Regulator TID test (S. Duzellier, ESA QCA





Current consumption during HDR TID test. Steps 4 and 5 correspond to annealing steps.





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Most common SEE expected on mixed signal ASICS

1. SEL. It appears as an steady overcurrent consumption in CMOS and Bi-CMOS ASICS, can only be stopped powering OFF the device.
2. SET. Voltage or current transient, may appear in analog outputs of both CMOS and bipolar ASICS.
3. SEU. Bit flip on a digital register or memory.
4. SEFI. Functional interruption due to a SEU in a state register that leads to a forbidden state. Recovery after soft or hard reset.

This SEE list is not exhaustive, refer to **ECSS-E-ST-10-12** for more details.

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General SEE testing tips

1. Tested usually using a heavy ion beam up to a LETth > 60 MeV.cm2/mg. Proton beams can be used when LETth < 15 MeV.cm2/mg.
2. Saturation cross-section and LET threshold are key parameters that shall be obtained in SEE testing.
3. Tune beam flux to allow the correct detection of all events, reduce detection dead time.
4. Use beams with enough penetration to reach the sensitive volume.
5. Open packages properly before heavy ion beam testing.
6. Any SEE mitigation circuit or technique shall be verified by radiation testing.

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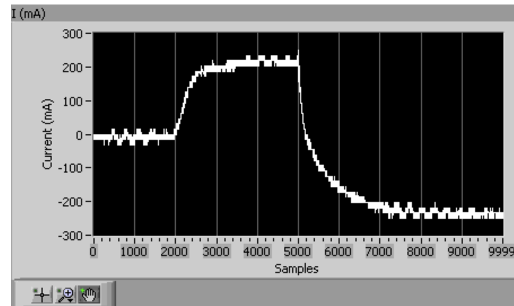
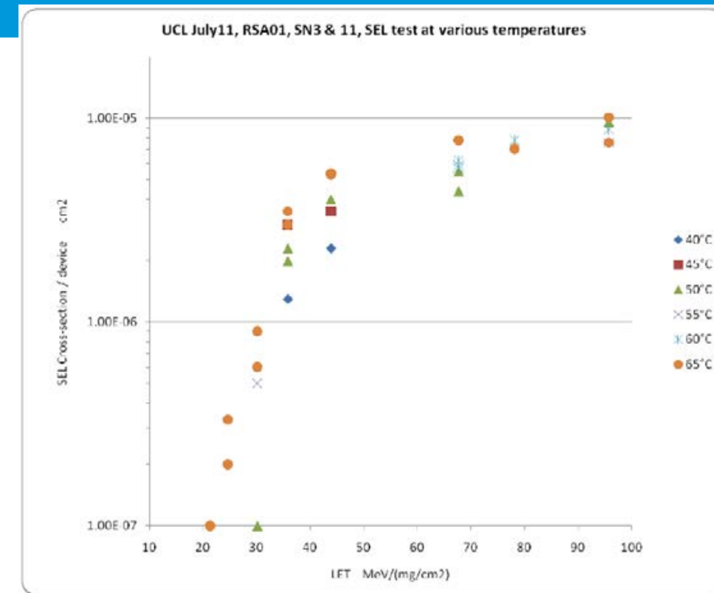
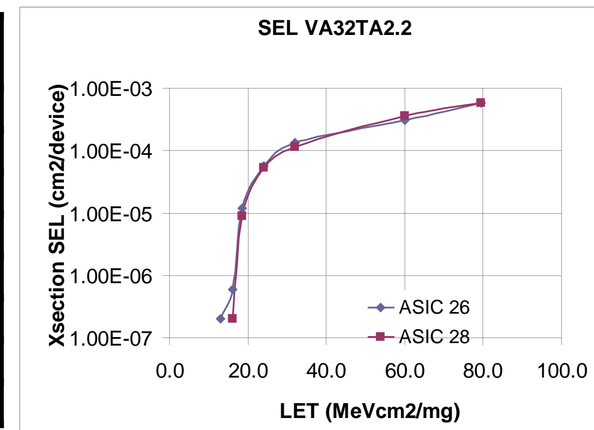
SEL testing tips

1. SEL may appear in CMOS and Bi-CMOS ASICs.
2. SEL is potentially destructive, it can only be stopped by completely powering OFF the ASIC.
3. Both high current and low current SELs can occur
4. SEL sensitivity increases with Vcc and temperature.
5. SEL may be mitigated by a system that detects overcurrent and triggers a power cycle but some devices may fail before the mitigation system reacts.
6. SEL sensitive devices should be avoided.





Ion	Energy [MeV]	Tilt [degrees]	Range [µm]	LET [MeV.cm2/mg]
Ar	372	0	118	10.1
Ar	372	39	118	13.0
Ar	372	51	118	16.0
Ar	372	57	118	18.5
Fe	523	40	97	24.2
Kr	768	0	94	32.1
Xe	1217	0	89	60.0
Xe	1217	41	89	79.5



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SEU & SEFI testing tips

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1. SEUs on internal memories may produce SEFI, SEU test setups should be prepared to deal with SEFI.
2. SEFI is in most cases only recovered after a hard reset.
3. Sometimes SEFI is confused with soft SEL.
4. ASIC digital technologies smaller than 90nm may be sensitive to proton ionization.
5. Most SEUs will be detected on digital outputs like communication registers.
6. Mitigation techniques like CRC and EDAC can be used to avoid error propagation through the communication ports.

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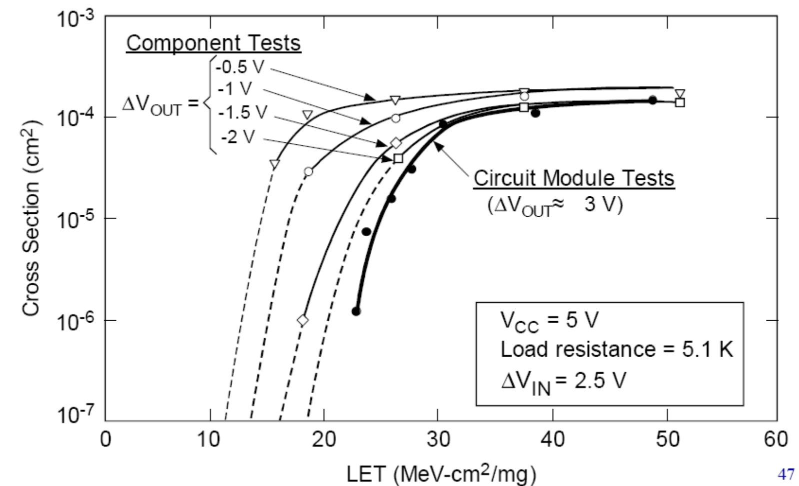
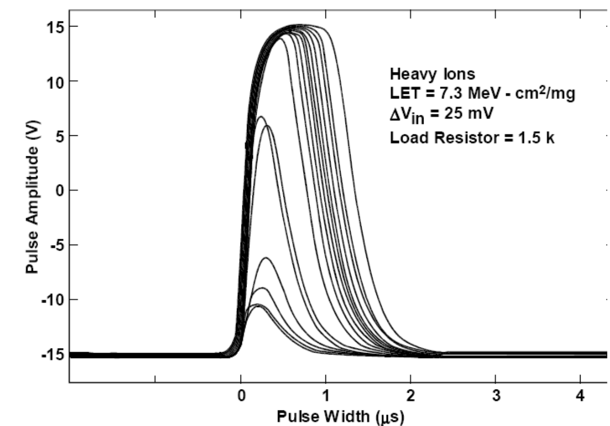
SET testing tips

1. Affects directly analogue outputs and may be critical when appears in amplification chains.
2. Internal SET may become SEUs.
3. SET strongly depends on bias conditions and frequency.
4. Cables used in SET detection must be carefully chosen as they may filter the event.
5. Possible mitigation options are TMR, filtering analog IO's and reducing the clock frequency.





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ESA Irradiation Test Facilities & ESA supported test facilities.

- ESA Test Facilities.

  - ESTEC Co-60 Facility. Facility used for TID testing.

- ESA Supported External Facilities

  - HIF and PIF facilities at the Université Catholique de Louvain (UCL), Belgium.
    SEE and Displacement Damage testing.

  - RADEF at Jyväskylä University, Finland.
    SEE and Displacement damage testing.

  - PIF (Proton Irradiation Facility) at PSI (Paul Scherrer Institut), Switzerland. Suitable for proton SEE testing due to its high energy beam (more than 200 MeV protons) and optical devices testing and calibration (TID and TNID).

Refer to https://escies.org for more detailed information on ESA supported and other European test facilities.

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Conclusion

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1. Mixed signal ASICS are complex devices that need extensive radiation testing in order to assure radiation hardness.
2. These devices may be sensitive to a number of radiation effects, TID, TNID, ELDRS, SEL, SEU, SET, SEFI ...
3. Pay special attention to application conditions (biasing, temperature, frequency).
4. There is also a number of radiation mitigation systems, techniques that can be applied but all of them shall be submitted to radiation testing in order to verify their performance.
5. In case of doubt always refer to a radiation expert as soon as possible. Late changes are always more complex, tedious, expensive ...

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