Impact of Spacecraft Shielding on Direct Ionization Soft Error Rates

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Outline

• Introduction
• Devices and sensitive volumes
  – 45 nm SOI SRAM (silicon)
  – 4 Gbit flash memory (SiO₂)
• NOVICE Rate Calculations
• Soft Error Rate Trends
  – Different environments
  – Soft error rates as a function of shielding in solid sphere geometry
  – Comparison to example calculation for actual spacecraft shielding
• Conclusions

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Results for 45 nm SRAM

Note difference in rates for “spherical shell” and “box in spacecraft”
Introduction

• 3-D ray trace / solid angle sectoring techniques used to evaluate complex shielding geometries for space missions

• SEE requirements often determined from simple assumptions about shielding

• Due to increasing sensitivity of scaled devices, traditional techniques may no longer be valid for direct ionization rates
  - Direct ionization upset by protons in 65 and 45 nm SRAMs
Introduction

For modern technologies, the relative soft error rates of different space radiations is not known under flight conditions:

- Direct ionization upset by protons
- Shielding is important for solar particle event radiation
- Galactic Cosmic Ray (GCR) rates, especially solar minimum, are widely quoted as “worst case”
Sensitive Volume Parameters

Samsung 4 Gbit NAND Flash

- Material: SiO₂
- Width: 63 nm
- Length: 50 nm
- Thickness: 10 nm
- \( Q_{\text{crit}} = 0.06 \) fC
- \( E_{\text{crit}} = 6.6 \) keV


IBM 45 nm SOI SRAM

- Material: Si
- Width: 450 nm
- Length: 450 nm
- Thickness: 100 nm
- \( Q_{\text{crit}} = 0.5 \) fC
- \( E_{\text{crit}} = 11 \) keV


Provides clear definition of SEU to compare soft error rates for different shielding configurations and environments
NOVICE Rate Calculations

Environment

Complex Shielding

Use detailed CAD files

\[ \Delta E \text{ in sensitive volume} \]

\[ \# \text{Events} > E \]

Energy (E)

NOVICE Event Rates for CREME96 and Other Environments

• Highly Elliptical Orbit at 28.5° inclination
• Rates due to direct ionization
  – Includes elastic reactions for incident protons
• Spot checks show agreement with CREME96 rates to within factor of 2 for spherical shielding

Reveals behavior of specific devices’ event rates, using critical energy, as a function of shielding depth/type and environment

45 nm SOI SRAM Soft Error Rates

- Shielding has significant impact on both solar event radiation (SPE and PSYCHIC) and trapped protons, but not GCR

Trapped proton environment dominates error rate under ambient conditions
4 Gbit NAND Flash Memory
Soft Error Rates

- Silicon dioxide sensitive volume
  - Not available in CREME96
- Similar behavior to silicon SRAM sensitive volume, except...

Trapped protons only exceed GCR-levels under ambient conditions for shielding thicknesses less than 13 mm (500 mil)
Analysis for Memory in Spacecraft

- Spacecraft (i.e., S/C) has ~800 kg dry mass
- Central Instrument Data Processor Box (i.e., electronics box or EB)
  – Aluminum walls 1.8 to 7.3 mm thick

Provides realistic environment for soft error calculations

Effect of Spacecraft Shielding on the 45 nm SOI SRAM Soft Error Rate

Aluminum spherical shielding overestimates soft error rates for these sensitive technologies

Conclusions

• Simplified assumptions of solid sphere shielding generally overestimate soft error rates due to direct ionization
  – Can be especially important in modern commercial devices
  – May lead to overdesign and increased mission cost

• For the examples examined here, soft error rates were overestimated by ~2x to ~40x
  – Largest errors for SPE worst case, SPE average, and trapped protons
  – This is analogous to TID and DDD requirement trends with shielding analysis
Conclusions

• For the two memories considered here:
  – Trapped proton environment, not widely quoted GCR environment, always contributed substantially and often dominated the soft error rates under ambient conditions
  – Average solar particle environment can cause more soft errors than GCR over the long-term during solar maximum
  – More shielding configurations & orbits should be analyzed

• Due to the increasing importance of shielding analysis for SEE, tools like NOVICE and Geant4-based applications (CRÈME-MC and SPENVIS/MULASSIS) are becoming necessities

• These tools need to be validated with space data
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Questions?