Cosmic Ray Effects on Micro-Electronics (CRÈME) Tools

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CRÈME Website

- ISDE hosts the CRÈME tool suite for predicting on-orbit error rates and proton total ionizing dose in microelectronics
- While there are multiple open-access options available, none are U.S.-based and controlled except for CRÈME
- ISDE maintains the code and operation of CRÈME, ensuring trust as well as continuing access
- Supports over 2000 users!

https://creme.isde.vanderbilt.edu
• **Single event effects** are unwanted or erroneous responses triggered by the passage of a high energy particle through the active region of that device
  
  • e.g. single event upset (SEU) in memory cells

• **Total ionizing dose** due to protons and electrons causes devices to suffer threshold shifts, increased current leakage (and power consumption), timing changes, decreased functionality

• Others not addressed by CREME
CRÈME Environments

- **Near-Earth particle environment (Sawyer & Vette ‘76)**
  - Extracted from tables of AP8 proton fluxes
  - User selects between solar minimum and solar maximum
- **Geomagnetic shielding (Nymmik ‘91)**
  - Precomputed vertical cutoff magnetic rigidity values
  - Generates a geomagnetic transmission function (percent vs rigidity)
  - User selects between quiet and stormy conditions
- **Galactic cosmic ray environment (Nymmik ’92)**
  - Relates intensity to Wolf sunspot number
  - Typically transported through spherical shell shielding
  - Reduced to linear energy transfer spectrum
- **Solar particle events**
  - Based on the October 1989 event, provides worst-week, worst-day and peak 5 minute fluxes
Ground Test: Proton-induced Cross Section

Cross-section (cm$^2$/bit) = # of errors / (fluence $\cdot$ #bits)

After Petersen, NSREC SC, 2008
Proton Event Rate Predictions (Circa 1980)

SEE On-Orbit Rate = \( \text{Measured Cross Section over a certain energy} \times \text{Space proton Flux at the energy} \ dE \)

- **Graph:**
  - **X-axis:** Proton Energy (MeV)
  - **Y-axis:** Cross Section (cm\(^2\)/bit)
  - **Legend:**
    - \(10, 100, 1000\) MeV

- **Graph:**
  - **X-axis:** MeV/nucleon
  - **Y-axis:** Particles/cm\(^2\)-sr-MeV/nucleon
  - **Legend:**
    - \(H\)
Ground Test: Heavy Ion Cross Section

Cross-section (cm$^2$) = # of errors / fluence

After Petersen, NSREC SC, 2008
Ion Event Rate Predictions (Circa 1980)

- Pickel and Blandford investigated upsets in silicon NMOS dynamic RAM
- Introduced right parallelepiped (RPP) sensitive volume
  - Diffusion ignored
- Sensitive region transistor diffusion, connected to storage capacitor
- Sensitive volume approximated as 21 µm x 3.5 µm RPP
- Integration over path length distribution yields rate

\[ Q_{\text{crit}} = 0.25 \text{ pC} \]

SEUs from Lightly Ionizing Particles

- Decreasing features sizes have lead to a reduction in critical charge
- With $Q_{\text{crit}} < 1 \text{ fC}$ SRAMs have become sensitive to effects from lightly ionizing particles

**Protons**

Sierawski, IEEE TNS 2009

**Muons**

Sierawski, IEEE TNS 2009

**X-rays**

King, IEEE TNS 2013
Estimated SEU rates: GEO

- SEU rates are dominated by electron environment if critical charge is low enough and geometry is large enough.
- This is true for other particles environments.

Monte Carlo Rate Predictions

- Environment descriptions
- Delta rays
- Nuclear reactions
- dE/dx variation
- Event rate predictions
- Detailed material structures
- Multiple sensitive volumes

- Flux (m²-sr-keV/nucleon⁻¹)
  - Kinetic Energy (MeV/nucleon)

- Counts
  - Energy (MeV)

- Event Rate (bit/day⁻¹)
  - Energy (MeV)
RadFx Missions

- Launched Oct. 8, 2015 on board Atlas 5 from Vandenberg, CA
- Achieved 800 – 500 km, 65° inclination orbit
- Carries Vulcan payload (1 LEP) with 8 x 4Mb SRAM (ISSI IS64WV25616B) SEU experiment
- Nearly world-wide radio coverage provided by amateur radio community
  - Reports single event upsets, resets, power
Conclusions

• Combating evolution of environments, devices, and tool use by
  • Incorporating AP9, updating GCR and geomagnetic models
  • Applying Monte Carlo methods to capture device response
  • Developing an API to access CREME96 calculations
  • Operating a CubeSat program to generate on-orbit datasets for advanced memories

• Collaboration with partners is necessary for continued improvement
References


