Radiation Effects and COTS Parts in Smallsats
Who We Are and Why You Should Listen

• Jonny Dyer, Chief Engineer, Skybox Imaging
  • Commercial missions that are cost-constrained, but must be reliable and long-lived to produce revenue

• Doug Sinclair, Owner, Sinclair Interplanetary
  • 19 LEO missions launched to date
  • Hardware launched in 2003 still working
  • Some educational failures too
Rad Hard Approach

- Guaranteed high-dose performance
  - High radiation deep space missions
  - “Failure is not an option” crewed missions
- Old technology, custom fab process, low integration, part-level testing/screening
  - Expensive, long lead times, high part counts

Hermetic / Hybrid = $$$

Many discretes on a deep space board

Juno’s “Now that’s some radiation” vault
Buy and Fly Approach

- Industrial and consumer products
- Very low cost, high performance
- Little knowledge of design details
- Suitable for educational missions, or very short duration flights

- If 90% of commercial ICs will tolerate an environment, and a device has 10 ICs, probability of mission success is only 35%.
Careful COTS

Identify Requirements for Careful COTS Device

Define Orbit and Duration
Define Shielding
Evaluate the Environment

Is TID > 30 krad?

Yes

Detailed Design
Best Practices
Buy Parts in Lots
Build Prototypes
Radiation Test
Post-Test Analysis

No

Test Passed?

Yes

Design is Qualified
Begin Flight Manufacture

No: Reduce duration or increase shield

No: Change design and re-test

Test Passed?

Yes
Environment - Input

• Orbit parameters, target lifetime, solar cycle
• Radiation sources:
  • Trapped particles (protons + electrons) – van Allen belts
  • Solar particles
  • Galactic Cosmic Rays (GCR)
Environment – Spectra and Shielding

• Model environment with SPENVIS

• Flux AND energy important – Spectra
  • Average spectra useful, but flux not uniform temporally or geographically!

• Shielding attenuates some particles
  • Effectiveness: Electrons > Low energy protons > high energy protons

• Heavy ions – low flux, big damage!

Global Flux at 600km and the South Atlantic Anomaly
SSC13-IV-3 August 13 2013
Environment LET and TID

- **Linear Energy Transfer (LET)**
  - Rate at which a particle loses energy moving through matter (material dependent)
  - Higher LET -> higher probability of single event effect
  - LET \( \propto \) stopping power – effectiveness of shielding

- **Total Ionizing Dose (TID)**
  - Measure of accumulated material damage due to ionizing radiation over time
  - For particles \( \sim \) LET x Fluence
Radiation effects and damage mechanisms

• Single Event Effects
  • “Event in time” – associated with single particle strike
  • Effects range from annoying to catastrophic
  • Single Event...
    • Upset (SEU) – bit flip in memory
    • Latch-up (SEL) – Parasitic SCR “short”
    • Burn-out (SEB) – Destructive transistor short
    • Functional Interrupt (SEFI) – Digital reconfiguration (FPGA, registers, etc)

• Cumulative Effects
  • MOS transistor threshold voltage changes (TID)
  • Bipolar transistor gain drops (TID + Displacement Damage)
  • Optical lenses/fibers turn brown
Design Best Practices

There are circuit design techniques that will increase survivability

• Choose lowest supply voltages and duty cycles
  • Low bias reduces SEL. Massive derating reduces SEB.
  • Zero bias eliminates single event effects, and reduces TID effect.

• Reduce number of different ICs
  • Few massively integrated parts more likely to succeed than many less complex parts

• Plan for SEUs
  • Make sure no I/O pin reconfiguration can cause damage
  • Find COTS memories with built-in ECC
  • Implement software ECC where hardware ECC unavailable
Radiation test options

- Gamma source (Co-60, etc)
  - TID only, no SEE
  - Cheap ($)
- Proton
  - TID and displacement damage
  - SEE up to LET ~ 25 MeV-cm²/mg from heavy ion generation
  - Need cyclotron / synchrotron to get high enough energies
  - More Expensive ($$)
- Heavy Ion
  - Primarily high energy SEE
  - Low energy source – must decap parts
  - High energy source – massive facility
  - Very expensive ($$$)
Evaluating Test Success

- Test 2 boards, built from controlled flight-candidate lots
- Board #1 test to expected dose
- Board #2 test to 2x expected dose
- Anneal boards following dose

- If both boards survive, unconditional success
- If board #1 survives but board #2 fails in cumulative dose, marginal success
  - Either reduce design life by 50%, or add shielding (bulk or spot)
- If both boards fail, or any destructive SEE seen, test unsuccessful
  - Must revise design and re-test
Typical Failure Mechanisms

• TID and Displacement Damage
  • Drift in analog components – voltage refs. usually first to go
  • Increased leakage, timing / propagation change, eventual failure in digital electronics

• Single Event Effects
  • Unacceptably high SEU (need ECC)
  • Destructive SEL (CMOS) or SEB (N-MOSFET)
  • Hardware reconfig SEFI – FPGA’s, complex CPU / MCU
Why we like our approach

• Modern high-performance tightly-integrated parts
  • Low mass, volume and power of final product
  • Overnight availability allows rapid design revision
  • Technology familiar to many non-space engineers

• Quantified radiation lifetime
  • Test at the board level with protons, most closely simulating the space environment
  • Satellite owners can make sensible business decisions
  • We all sleep better when hope is replaced by certainty