Radiation and Reliability Considerations in Digital Systems for Next Generation CubeSats

Enabling Technology: P200k-Lite Radiation Tolerant Single Board Computer for CubeSats

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Topics

• CubeSats for high-reliability missions
• Electronic system reliability overview
• Radiation effects background
• Radiation’s role in system reliability
• Parts stress and parts selection
• Space Micro’s approach to CubeSat hardware
• Enabling technology for future CubeSat missions
Typical CubeSat Missions

• Short duration
  • 30 – 90 days
  • Some survive years

• Friendly orbits
  • Low inclination
  • Low altitude
  • Example: ISS

• Low priority, high acceptable risk

CubeSats deployed from ISS. Image credit: NASA
Future CubeSat Missions

• Longer duration
  • 2+ years requirement
  • 5+ year goal
• Harsher orbits
  • High inclination
  • Higher altitude
  • GEO
  • Interplanetary
• Higher priority, lower acceptable risk

JPL’s INSPIRE Project. Image credit: NASA/JPL-Caltech
Hi-Rel Space Hardware Must Consider...

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<tr>
<th>Launch Environment</th>
<th>Thermal Environment</th>
<th>Radiation</th>
<th>Reliability</th>
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<tr>
<td>• Shock</td>
<td>• Temperature range</td>
<td>• Total ionizing dose (TID)</td>
<td>• Screening</td>
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<td>• Vibration</td>
<td>• Temperature cycling</td>
<td>• Single event effects (SEE) (destructive and non-destructive)</td>
<td>• Qualification</td>
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<td></td>
<td>• Conductive Cooling</td>
<td></td>
<td>• Quality</td>
</tr>
<tr>
<td></td>
<td>• CTE</td>
<td></td>
<td>• Stress</td>
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- Many of these are related
- This list is not exhaustive
- Lot of other concerns (example, outgassing & prohibited materials)
Reliability Overview

• Measured in mean time to failure (MTTF)* or failures in time (FIT)
• Mission reliability often specified as X% at Y years
  \[ X = 100e^{-\left(\frac{Y}{MTTF}\right)} \]  for constant failure rate
• X is your reliability budget
• Margin is difference between specified reliability and calculated reliability
• Example: FIT of 1100 failures per billion hours ≈ MTTF of 104 years ≈ 95% reliability at 5 years

*MTTF is often used interchangeably with mean to between failures (MTBF)
Reliability Depends On...

• Radiation
• Parts (process, quality, screening, etc)
• Temperature
• Stress
• Many other things
Radiation Concerns

- Trapped in radiation belts, from the sun, and from the depths of the galaxy
- Radiation affects performance of most semiconductor devices
- Both cumulative effects (TID) and “random” effects (SEE)
- Heritage doesn’t matter, data matters

Inner and Outer Radiation Belts, from GSFC website
Total Ionizing Dose (TID)

- TID can’t be ignored since CubeSats typically offer limited shielding, but it is relatively easy to address
- Lots of TID data available, TID hard parts available
- TID is increasingly less of a problem in modern parts
Single Event Effects (SEE)

- SEE are undesirable effects caused by a single charged particle striking a sensitive region in the device.
- Testing requires particle accelerators that are very expensive and book up months in advance.
- SEE are an increasingly big problem in CMOS devices with fine feature sizes, such as microcontrollers and processors.
- Unlike TID, shielding is not effective mitigation.
Destructive SEE

- Single Event Latchup (SEL) is a high current state caused in CMOS devices when a single energetic particle induces a parasitic thyristor (pnpn) shorting to ground, and can be destructive.

- SEL is a significant mission threat, especially for CubeSats using COTS microcontrollers or processors.

- Latchup protection circuitry is not very effective and difficult to properly implement, especially with complex parts such as processors.

Arrow represents ion track of a galactic cosmic ray inducing SEL in CMOS.
SEL in COTS microcontrollers

“Only” 5% Is that good?

Calculated probably of SEL within 5 years for six COTS microcontrollers with published data for various orbits.
SEL rates & reliability margin

• Even the best microcontroller had a 5% chance of destructive SEL within 5 years in polar orbit.

• At first glance, that might seem acceptable, but let’s review our reliability budget

  95% Reliability at 5 years

• In this case, a single failure mode of a single device consumes the entire reliability budget
SEU and SEFI

• Single event upsets (SEU) and Single Event Functional Interrupts (SEFI) are non-destructive, but that doesn’t mean they don’t matter.

• SEU Example: bit flip in a memory device

• SEFI Example: bit flip in control logic, causing device to hang, requiring external intervention

• Newer parts are extremely sensitive
  • Lower voltages
  • Finer feature sizes
  • Advanced memories might see many SEU or SEFI every day, which could cripple a system
Parts Selection and Derating

• Spend money where it will go the farthest
  • COTS can serve a big purpose if used appropriately
  • MIL grade does not mean radiation tolerant

• Do what you can
  • No SWaP budget for redundancy

• Parts failures can be drastically reduced through derating

• Focus on the parameters you can control (e.g. voltage)

• Derating analysis is tedious, but identifies critical parts and can dramatically increase overall reliability

<table>
<thead>
<tr>
<th>1000pF 0603 Ceramic Capacitor</th>
<th>5V rated COTS part used at 5V</th>
<th>50V rated COTS part used at 5V</th>
<th>50V rated MIL part used at 5V</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIT at 25C</td>
<td>14.97</td>
<td>2.76</td>
<td>0.05</td>
</tr>
<tr>
<td>FIT at 55C</td>
<td>52.06</td>
<td>9.59</td>
<td>0.19</td>
</tr>
</tbody>
</table>

(Example using MIL-HDBK-217 Calc)
Space Micro’s approach

• Offer high reliability in small form factor
• Parts selection
  • Function
  • SWaP
  • Vendor/Quality
  • Reliability
  • Availability
  • Cost
• Design for reliability
• Radiation mitigation (sometimes includes testing)
P200k-Lite Development

• Development driven by Navy/SPAWAR CubeSat mission due to launch in 2015
• Mission required reliable C&DH for 2+ year polar orbit
• Trade studies indicated a significant lack of CubeSat flight computers designed for long duration missions
• Space Micro chose to design & build a radiation tolerant high reliability C&DH solution in the CubeSat form factor, leverage flight-proven Proton200k single board computer
P200k-Lite Specs & Capabilities

Processing Specs
• Floating Point DSP/FPGA based computing @ 900 MFLOPS
• 512 Mbyte SDRAM, 8Gb RH Flash, 1-8 Mbyte EEPROM
• 32Bit, 33MHz I/O bus, RS-422,I2C, 16 channels GPIO
• 8 Channel D2A, 4 Channel A2D
• 1.5W Operational power, <1/3W @ standby

Radiation/Reliability Specs
• >63 MeV-cm²/mg SEL threshold
• SEU detection/mitigation algorithms
• 30krad (Si), optional 100krad
• 100% SEFI recoverable, H-Core technology for SEFI detection/mitigation
• MTBF = 300 years.
• Toggle-able EDAC capability
Comparison to standard CubeSat C&DH

<table>
<thead>
<tr>
<th>Test</th>
<th>QT</th>
<th>AT</th>
</tr>
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<tbody>
<tr>
<td>Functional</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Vibration</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>Mechanical Shock</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>Thermal Cycling</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Thermal Vacuum</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>Total Ionizing Dose</td>
<td>-</td>
<td>-</td>
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</tbody>
</table>

QT is performed on the design/qualification model
AT is performed on the unit to be shipped

**Specifications**

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Processor:</td>
<td>400MHz ARM9 processor</td>
</tr>
<tr>
<td>Volatile Memory</td>
<td>32MB RAM</td>
</tr>
<tr>
<td>Data Storage</td>
<td>2x 2GB</td>
</tr>
<tr>
<td>Code Storage</td>
<td>1MB NOR Flash</td>
</tr>
<tr>
<td>FRAM</td>
<td>256 KB</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-20°C to +60°C</td>
</tr>
<tr>
<td>Power consumption</td>
<td>400mW average</td>
</tr>
<tr>
<td>Power supply</td>
<td>3.3V</td>
</tr>
<tr>
<td>Dimension</td>
<td>96 x 90 x 12.4 [mm] (including FM daughter board)</td>
</tr>
<tr>
<td>Mass</td>
<td>94g (including daughter board)</td>
</tr>
</tbody>
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P200k-Lite Applications

- Greater processing capability allows for higher density, more advanced sensors
- Onboard processing enables missions with limited downlink bandwidth
- Opens up a wide range of missions utilizing high reliability designs such as deep space and long duration missions not available to current CubeSats
Developing on the P200k-Lite

• P200k-Lite comes with basic firmware and software necessary to begin mission-specific development
• Custom SW/FW is also available at customer request
• Further SW/FW support is available
Summary

• The CubeSat community needs high reliability, radiation tolerant subsystems to enable next generation missions.

• Designers must take vertical approach and consider performance, SWaP, reliability, and radiation.

• Space Micro is developing CubeSat subsystems that meet the needs of long duration missions.
Questions?