SPACE MICRO

Radiation and Reliability Considerations in Digital Systems for Next Generation CubeSats

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

Clint Hadwin, David Twining, David Strobel

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

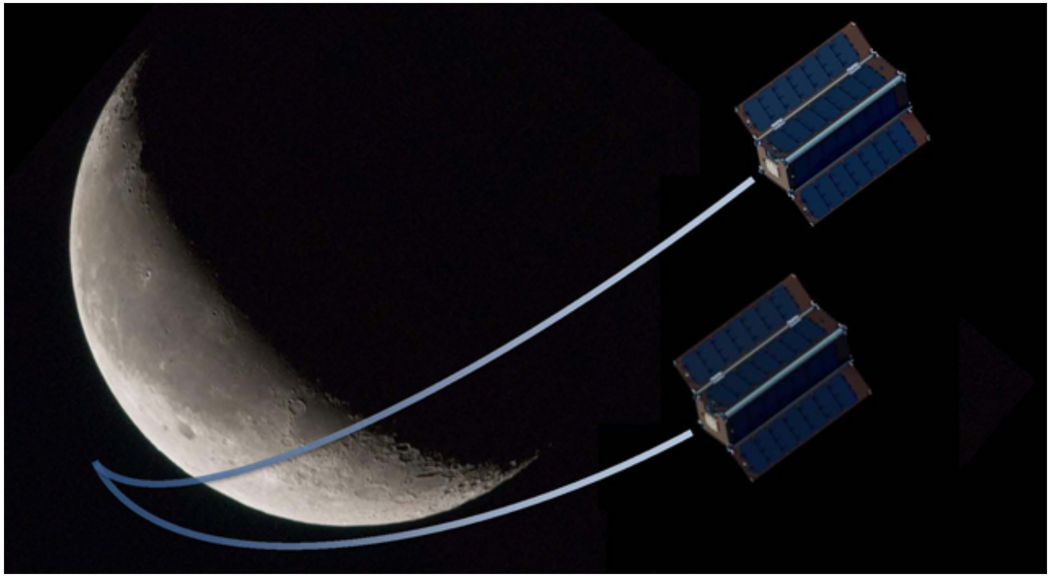
Typical CubeSat Missions

- 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…

Launch Environment	Thermal Environment	Radiation	Reliability
• Shock • Vibration	• Temperature range • Temperature cycling • Conductive Cooling • CTE	• Total ionizing dose (TID) • Single event effects (SEE) (destructive and non-destructive)	• Screening • Qualification • Quality • Stress • Derating • Failure rates

- 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

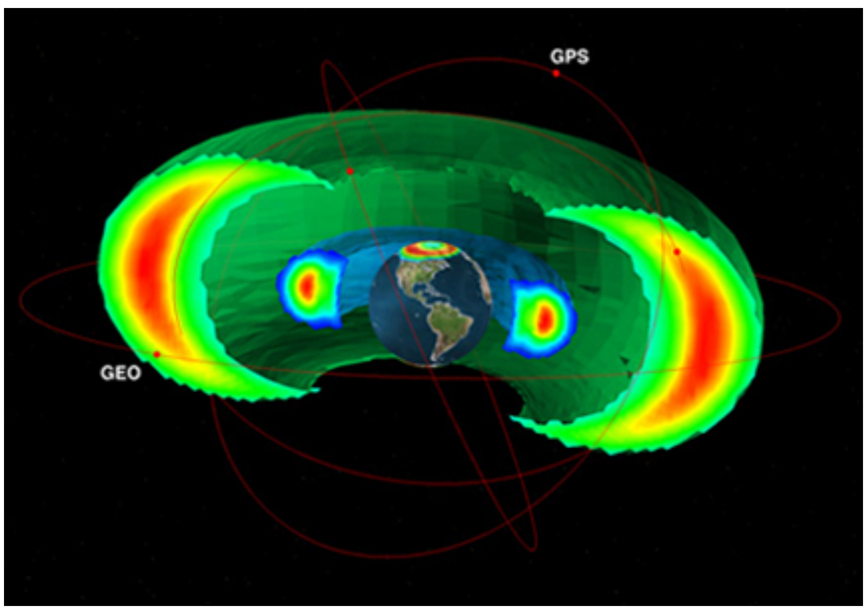
*MTTF is often used interchangeably with mean to between failures (MTBF)

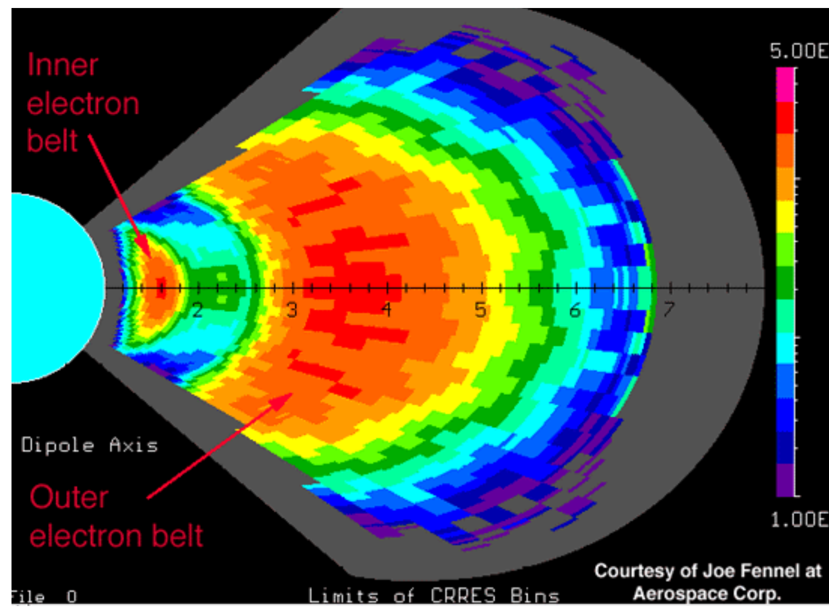
Reliability Depends On…

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

Radiation Concerns

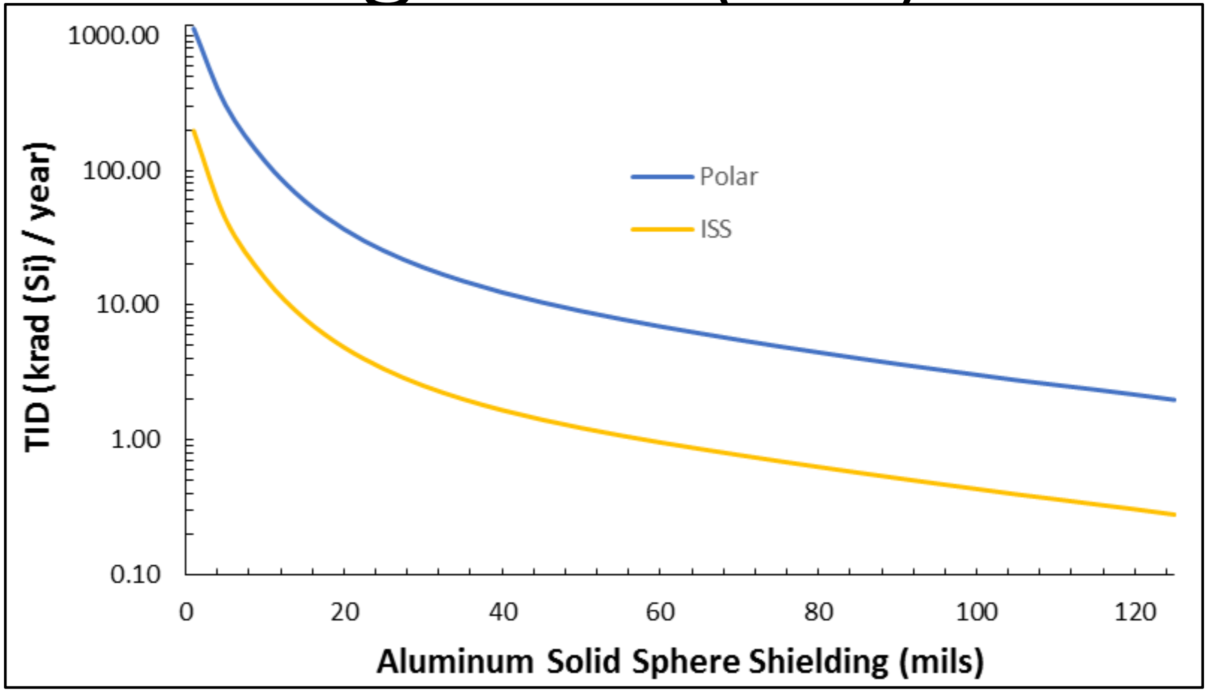
- Trapped in radiation belts, from the sun, and from the depths of the galaxy
- Radiation affects performance of most semiconductor devices
- Both cumulative effects (TID) and "random" effects (SEE)
- Heritage doesn't matter, data matters





Inner and Outer Radiation Belts, from GSFC website

Total Ionizing Dose (TID)

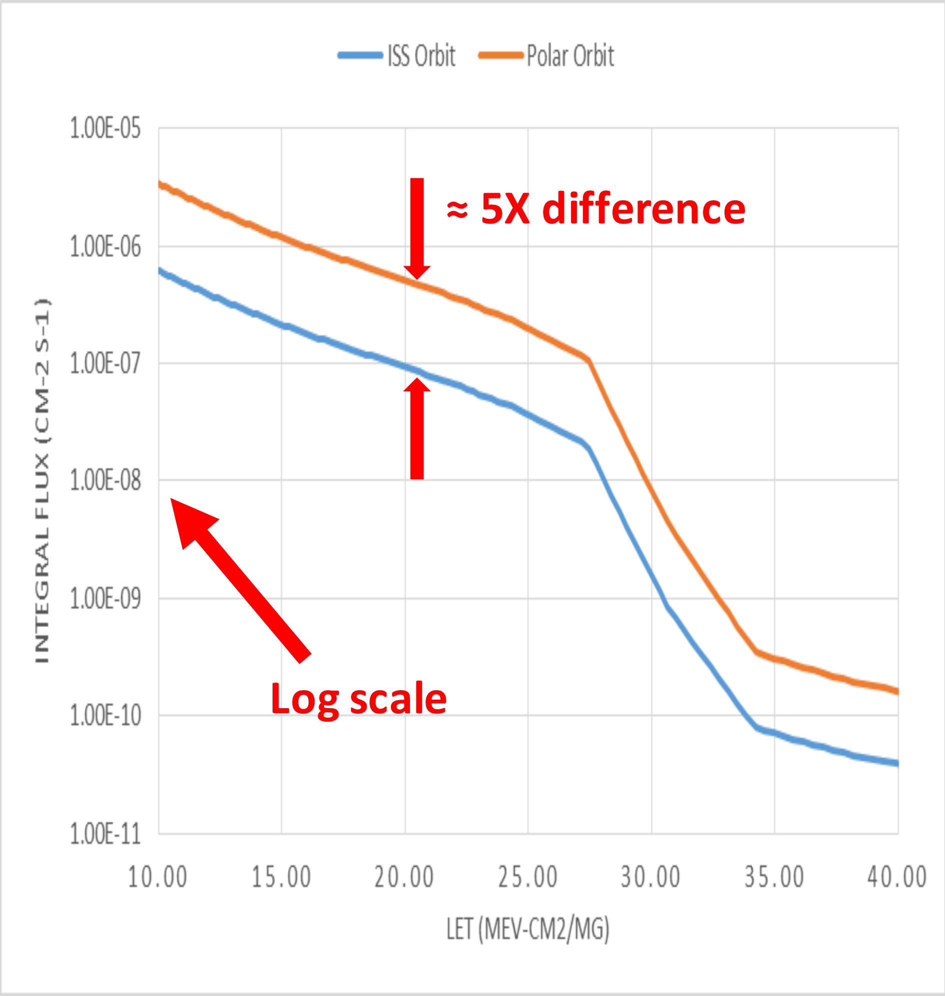


Annual dose depth curves for typical ISS and Polar orbits

- 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

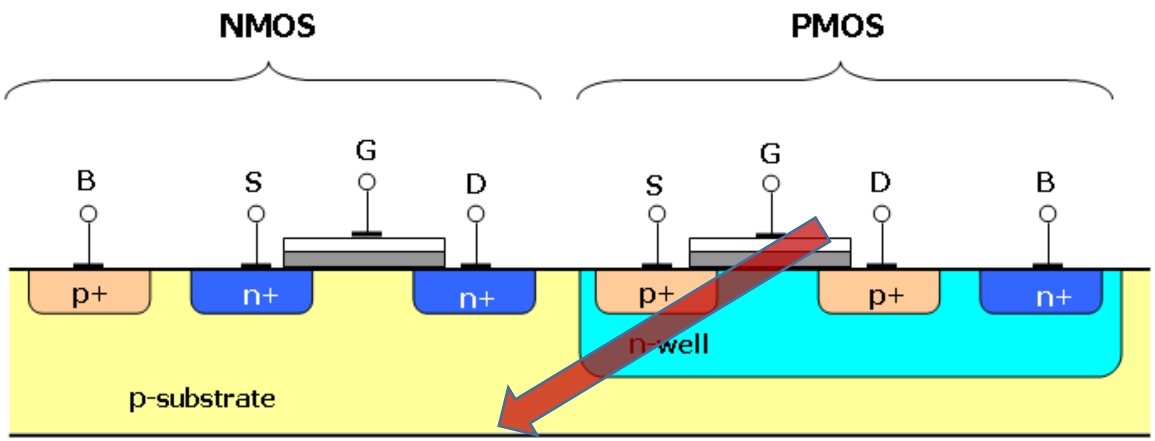
Single Event Effects (SEE)

- 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

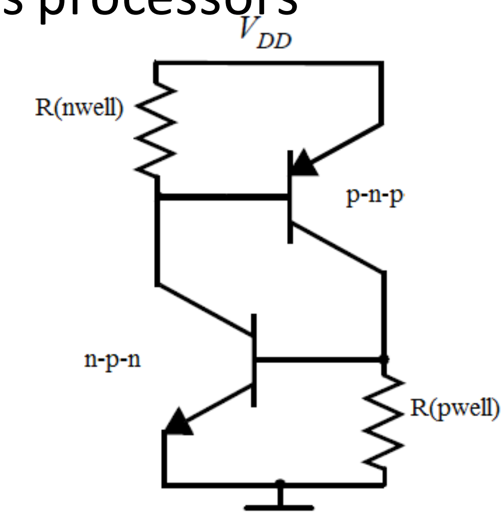


Destructive SEE

- 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

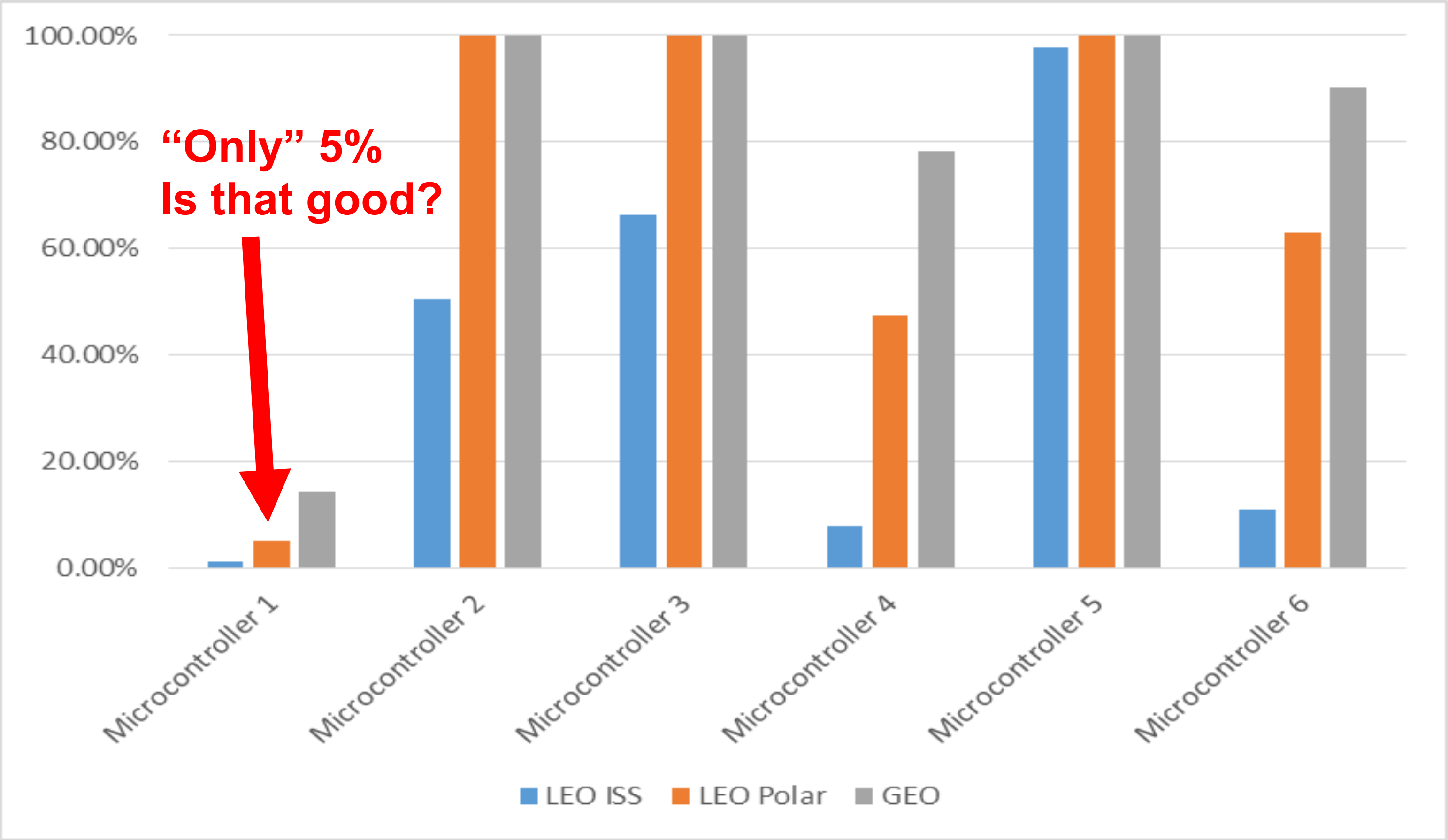


Arrow represents ion track of a galactic cosmic ray inducing SEL in CMOS



CMOS Latchup Equivalent Circuit

SEL in COTS microcontrollers



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

1000pF 0603 Ceramic Capacitor	5V rated COTS part used at 5V	50V rated COTS part used at 5V	50V rated MIL part used at 5V
FIT at 25C	14.97	2.76	0.05
FIT at 55C	52.06	9.59	0.19
(Example using MIL-HDBK-217 Calc)			

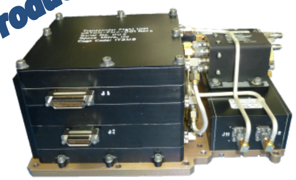
Space Micro's approach

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

RF COMMUNICATIONS	DIGITAL BOARDS/SYSTEMS	GN&C/INSTRUMENTS	COMPONENTS

RF Communications

Flight Production



uSGLS ™ Transponder

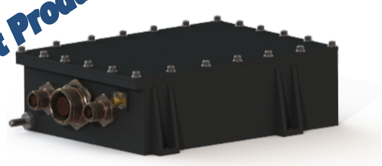
In Orbit Now

uSTDN™ Transponder

In Orbit Now

X-Band TX

Flight Production



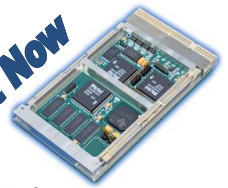
Ka-Band TX

Digital Boards/Systems

Flight Delivery

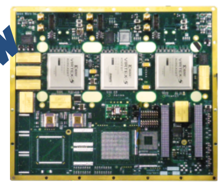
ProtonX-Box Avionics Suite

In Orbit Now



Proton200k DSP Processor Board

In Orbit Now

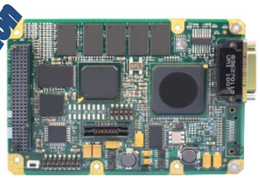


Proton300k Reconfig. Xilinx FPGA Bd

In Orbit Now

Proton100k for TacSat2

Flight Production



Proton400k

GN&C/Instruments

In Orbit Now

Image Processing Computer

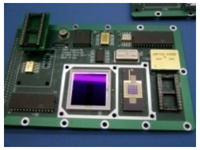
Flight Production

Star Tracker

In Orbit Now

Coarse/Medium Sun Sensors

Flight Delivery



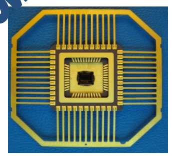
UVEPROM Dosimeter

Components

In Orbit Now

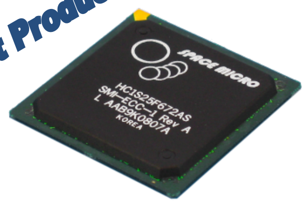
8 Gb RH Flash Module

In Orbit Now



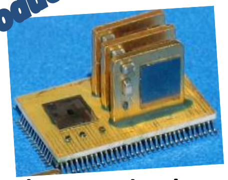
H Core™ IC

Flight Production



2.5 Gbps ECC IC

Flight Production

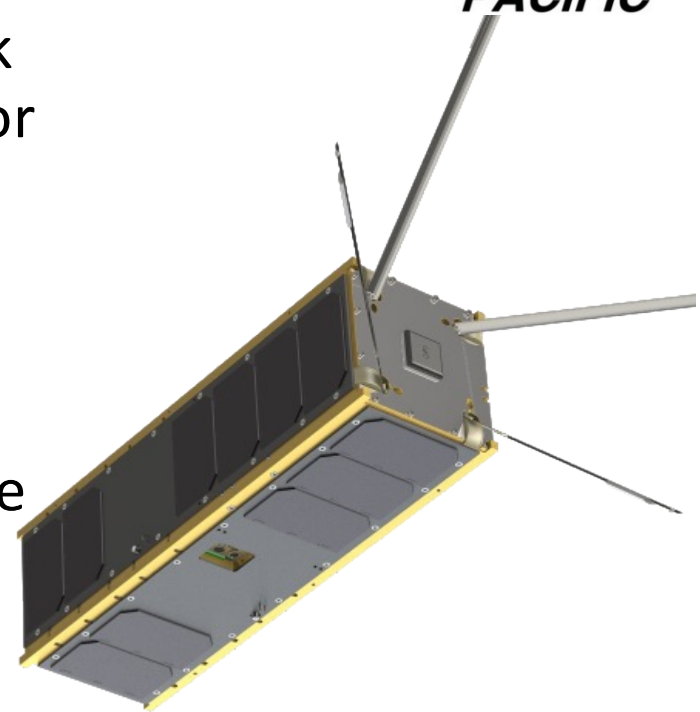


Divert Attitude Controller Module

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

SPAWAR
Systems Center PACIFIC



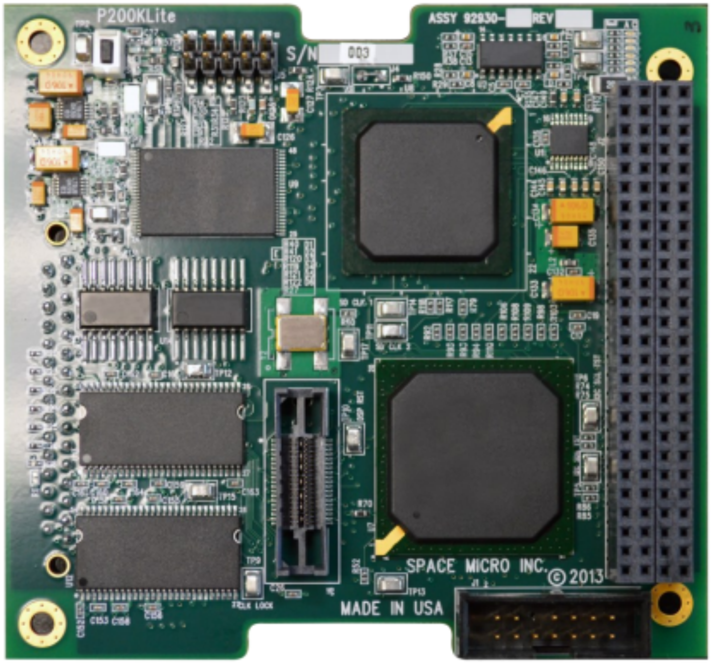
P200k-Lite Specs & Capabilities

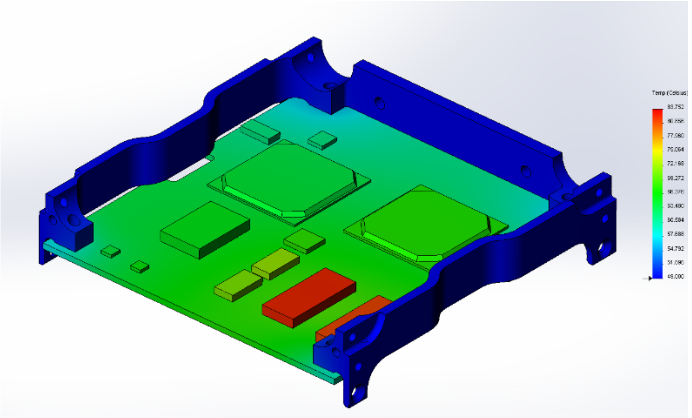
Processing Specs

- 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

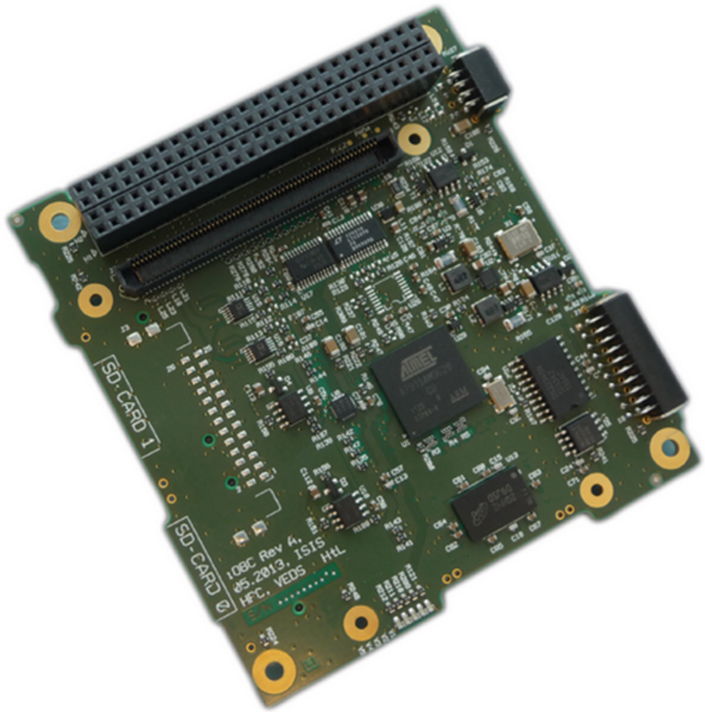
Radiation/Reliability Specs

- >63 MeV-cm^2/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



Qualification and Acceptance Testing

Test	**QT**	**AT**
Functional	✓	✓
Vibration	✓	-
Mechanical Shock	✓	-
Thermal Cycling	✓	✓
Thermal Vacuum	✓	-
Total Ionizing Dose	-	-

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

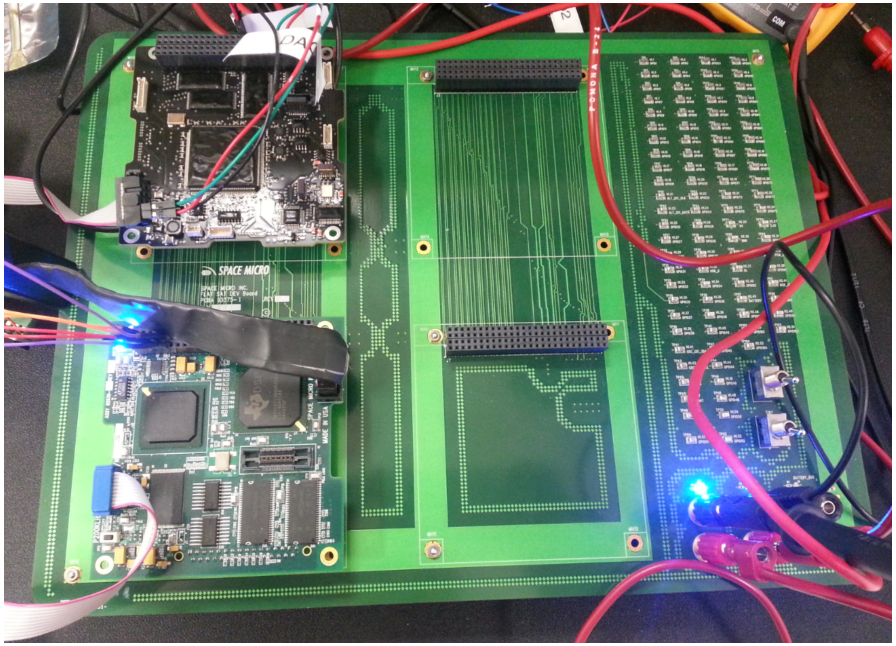
Specifications	
Processor:	400MHz ARM9 processor
Volatile Memory	32MB RAM
Data Storage	2x 2GB
Code Storage	1MB NOR Flash
FRAM	256 KB
Operating Temperature	-20°C to +60°C
Power consumption	400mW average
Power supply	3.3V
Dimension	96 x 90 x 12.4 [mm] (including FM daughter board)
Mass	94g (including daughter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

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?