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Space Radiation Mitigation for *Fox-1*

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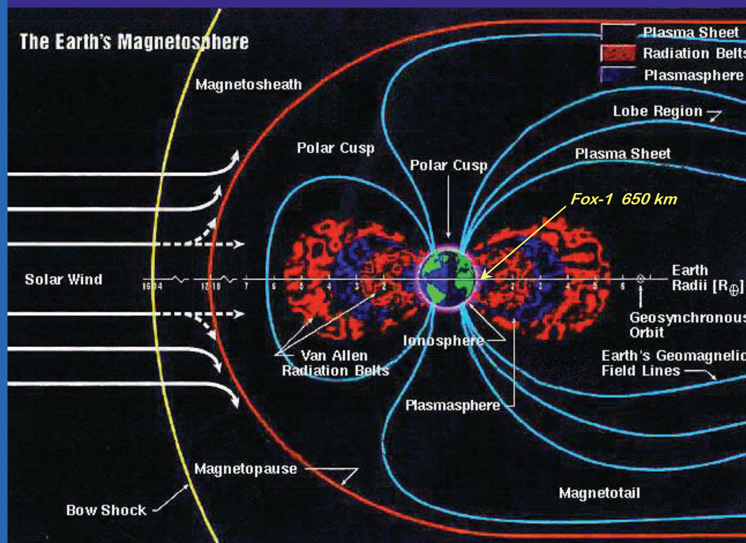
Space Radiation Components

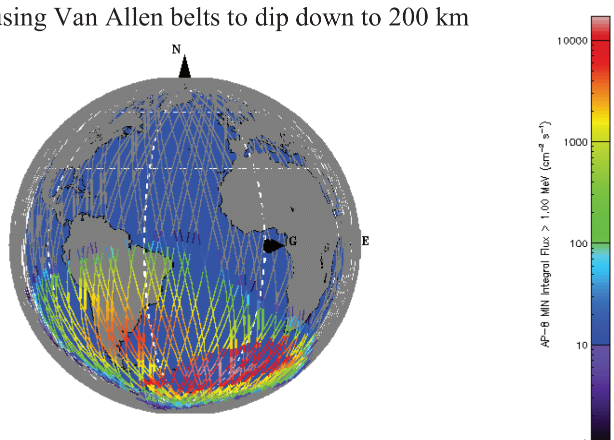
Type	Source	Composition
Trapped Particles in Van Allen Belts	Solar Wind	High Energy Protons (+ Anti-protons!) High Energy Electrons Bremsstrahlung (X-Rays)
Galactic Cosmic Radiation	Cosmic Rays	Hydrogen to Uranium Nuclei Low Flux, but Very High Energies
Solar Particle Events	Solar Flares and Coronal Mass Ejections	Energetic Electrons, Protons, Alpha Particles

Radiation in Orbit



South Atlantic Anomaly

- Earth's magnetic field non-concentric with rotation axis causing Van Allen belts to dip down to 200 km



- The major source of space radiation for *Fox-1*

Space Radiation Effects

- Total Ionizing Dose (TID)

  The result of all of the radiation that is absorbed by a component over time. Non-deterministic but expected ranges can be effectively modeled.

- Single Event Effects (SEE)

  The result of high energy particles. Can happen at any time - on first day or after many years in orbit.

Radiation Effects on Components

- Total Ionizing Dose (TID) causes components to gradually deteriorate like wear on a tire
  - Parameter drift
  - Electrical leakage in insulators
- Single Event Effects (SEE) cause immediate failure like a tire blowout from a sharp object
  - Failure can be temporary or permanent
  - Transient signals
  - Stuck-bits in logic devices
  - MOS gate rupture
  - CMOS latchup (SEL)

TID Modeling

- The radiation source model

  Various models applicable to different particles and solar conditions which each give significantly different results - picking the right one is part art and part science.

- The orbit, and expected solar activity

  Solar activity varies significantly over the short and long term - a Coronal Mass Ejection (CME) can deliver a years worth of radiation in a few days.

- The radiation absorption model used for the spacecraft components

Spacecraft Absorption Models

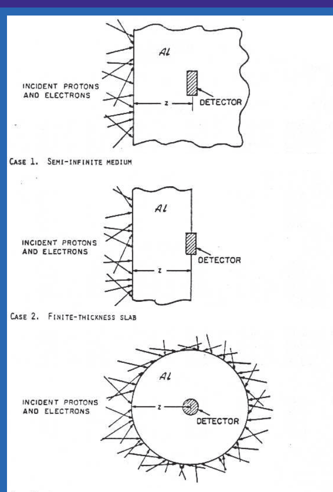
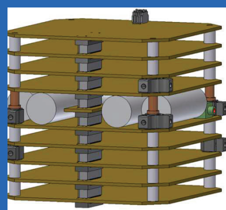


Illustration Courtesy of ESA/SPENVIS

No publically available models for a complete, general spacecraft. There are three basic geometries available.

1. Semi-infinite slab - models components near surface of spacecraft.
2. Finite slab - models spot shielded components.
3. Solid spherical shell - models components deep within spacecraft.

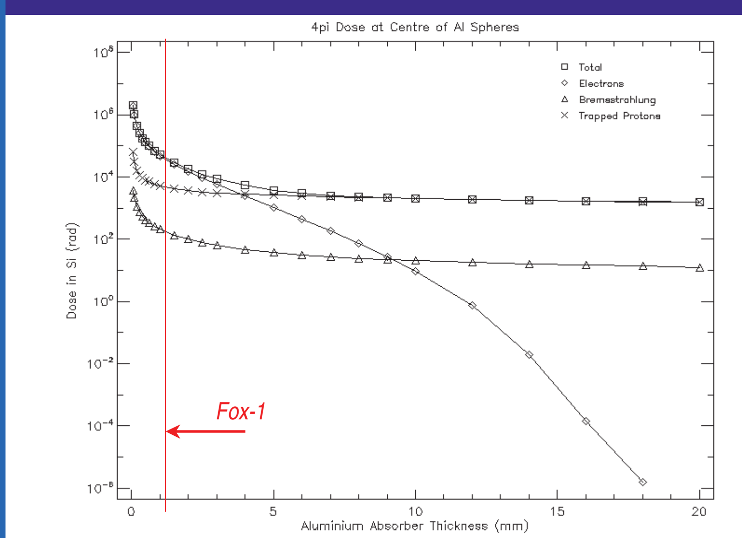
Calculation of TID Radiation



Given the *many* approximations, the spherical shell model is surprisingly applicable to most configurations.

- None of these models closely resembles a CubeSat. In order to develop a semi-quantitative profile for radiation deposition, select a radiation source profile and:
  - Pick the deposition model most appropriate to the satellite face.
  - Convert the component substances to the equivalent thickness of aluminum.
  - Calculate the radiation deposition between each surface and the opposite surface.
  - Superimpose the radiation contributions from each surface to get a ***very*** approximate 3 dimensional image.

Fox-1 Effective Shielding



Component Spot Shielding

- Tantalum or lead traditionally used for spot shielding of sensitive components to reduce TID
- Spot shielding can actually *create* additional radiation due to Bremsstrahlung
- Reductions in TID can result in an increase in SEE
- Use limited spot shielding of specific components if warranted

ESA SPENVIS TID Model

- 5 year mission lifetime
- 650 km polar orbit
- Include average contribution of shielding from structure and PCBs
- Spherical shell model
- Model shows "high" confidence that typical internal component TID < 30 kRAD

SEE Modeling

- Need to calculate the Linear Energy Transfer (LET) of a particle as it passes though components leaving a “contrail” of energy along its path.
- Single event effect occurs when energy deposited by a particle is above the component's $LET_{threshold}$
- Computer models require detailed component internal structure information - not a practical approach for AMSAT
- NASA data for LEO orbit shows low event probability above ~ 30 MeV-cm^2/mg

Overall Radiation Mitigation Strategy

- Satellite based on COTS parts
- Use radiation tested parts where possible
- Employ system-level radiation tolerance
- Very limited use of *rad-hard* parts
  - Solar cells are rad-hard
- Limited radiation spot shielding of specific components if warranted

Radiation Mitigation *Reality*

- It is not possible to eliminate all risks
- It is not possible to use only proven, tested components
- Reduce risks where possible
- Use conservative circuit design approaches
- Design for fault tolerance

Engineering Guidelines

- Prefer COTS parts that have been tested
  - TID > 30 kRAD
  - SEL > 30 MeV-cm2/mg
- Do not use parts that have tested poorly
- Space flight heritage - better than nothing
- Prefer discrete semiconductors to ICs
- ICs from TI tend to test well
- Untested or sensitive CMOS parts must have latchup protection circuitry (use FPF20xx)
- Passive components can generally be considered safe

Low Risks

- U310 family J-FETs
- 2N2222 type transistors
- LM139 comparators
- LM6142 op amps
- LT6233 low noise op amps
- TMP36 temp sensors
- DS1631 I^2C digital thermometers
- CD4000 & 74HCxxx logic generally OK

High Risks

- Any version of 555 timer
- Any part with an internal charge pump
- All low-dropout voltage regulators and high-side switches with N-channel or NPN pass transistors
  - LP2941 - LP2953
- BiCMOS linear components (op amps)
  - LTC2052
- Active temperature sensors
  - AD590
- Untested microprocessors & microcontrollers

NASA Derating Guidelines

PART TYPE	RECOMMENDED DERATING LEVEL
Capacitors	Max. of 60% of rated voltage
Resistors	Max. of 60% of rated power
Semiconductor Devices	Max. of 50% of rated power Max. of 75% of rated voltage Max. junction temperature of 110℃
Microcircuits	Max. supply voltage of 80% of rated voltage Max. of 75% of rated power Max. junction temperature of 100°
Inductive Devices	Max. of 50% of rated voltage Max. of 60% of rated temperature
Relays and Connectors	Max. of 50% of rated current

NOTE: Maximum junction temperature levels should not be exceeded at any time or during any ground, test, or flight exposure. Thermal design characteristics should preclude exceeding the stated temperature levels.

Space Radiation Resources

- NASA JPL: radcentral.jpl.nasa.gov
- NASA Goddard: radhome.gsfc.nasa.gov
- ESA : escies.org/labreport/radiationList
- IEEE papers
- NSREC conference papers
- Alan Biddle WA4SCA - consulting radiation engineer