CONFIDENCE LEVEL BASED APPROACH TO TOTAL DOSE SPECIFICATION FOR SPACECRAFT ELECTRONICS

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To be presented by Mike Xapsos at the 2017 NASA Electronics Parts and Packaging (NEPP) Electronics Technology Workshop (ETW), NASA/GSFC, Greenbelt, MD, June 26-29, 2017.
Outline

• Background
• Device Failure Distributions in Total Dose
• Total Dose Distributions in Space
• Device Failure Probability during a Mission
• Conclusions
  ▪ Failure Probability ($P_{\text{fail}}$) vs. Radiation Design Margin (RDM)
Space Environment Model Use in Spacecraft Life Cycle

Mission Concept
Mission Planning
Design
Launch
Operations
Anomaly Resolution

Space Climate
Minimize Risk

Space Weather
Manage Residual Risk

Both

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Radiation Hardness Assurance Overview

- Starting with mission requirements, methodology consists of 2 branches of analyses that lead to parts categorization
  - Parts analysis
  - Environment analysis
Radiation Hardness Assurance Overview

• Parts are categorized for flight acceptability and possible radiation lot acceptance testing by Radiation Design Margin (RDM).

  \[ \text{RDM} = \frac{R_{mf}}{R_{spec}} \]

• \( R_{mf} \) is mean failure level of part

• \( R_{spec} \) is total dose level of space environment

• Difficulties can arise because
  - Part failure levels can vary substantially from the mean, especially COTS
  - Environment is dynamic and must be predicted years in advance

• RDM based approach results from use of deterministic AP8/AE8 trapped particle models

• RDM used as a “catch-all” to cover all uncertainties in environment and device variations

• Propose modified approach
  - Use device failure probability during a mission instead of RDM

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Devices Tested

- Solid State Devices, Inc. SFT2907A bipolar transistors
  - Used for high speed, low power applications
  - 10 devices TID tested for MMS project at NASA/GSFC gamma ray facility to 100 krad(Si)

- Amptek, Inc. HV801 optocouplers
  - GaAlAs parts manufactured in liquid phase epitaxially grown process
  - 6 devices DDD tested for JUNO project at UC Davis Cyclotron with 50 MeV protons

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Device Failure Distribution
SFT2907A Bipolar Transistors

10 V collector-emitter bias
1 mA collector current

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• TID and DDD probability distributions were calculated for each orbit and mission duration for confidence levels ranging from 1 to 99%
  ▪ AP9/AE9 Monte Carlo code used to simulate 99 histories for each case
  ▪ ESP solar proton calculations done for 1 to 99% confidence levels
  ▪ All energy spectra were transported through shielding levels from 10 to 1000 mils Al using NOVICE code and converted to doses
  ▪ TID and DDD for each radiation were separately ranked for confidence levels ranging from 1 to 99% and summed for same confidence and shielding levels
TID Probability Distributions for 1 Year 10 – 1000 mils Aluminum

Low Inclination LEO

GEO

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Failure Probabilities
SFT2907A Bipolar Transistor

\[ P_{\text{fail}} = \int [1 - H(x)] \cdot g(x) \, dx \]

\( H(x) = \text{CDF for environment dose} \)
\( g(x) = \text{PDF for device failure} \)

Failure probability \( (P_{\text{fail}}) \) is the probability of a total dose failure during a mission.
Confidence Level vs. RDM for 10 years in GEO
200 mils Al shield
Conclusions

- An approach to total dose radiation hardness assurance was developed that includes variability of the space radiation environment.

- Examples showed radiation environment variability is at least as significant as variability of total dose failures in devices measured in the laboratory.
  - New approach is more complete
  - Uses consistent evaluation of each radiation in the space environment through use of confidence levels

- Advantages of using $P_{\text{fail}}$ instead of RDM are:
  - $P_{\text{fail}}$ is an objectively determined parameter because complete probability distributions are used to calculate it; gives designers more trade space
  - Better characterization of device radiation performance
  - Allows direct comparison of the total dose threats for different devices and missions, regardless of whether degradation is due to TID or DDD
  - More amenable to circuit, system and spacecraft reliability analysis
Acronyms

- AE9 – Aerospace electron model-9
- AP9 – Aerospace proton model-9
- CDF – cumulative distribution function
- COTS - commercial off the shelf
- DDD – displacement damage dose
- ESP – Emission of Solar Protons (model)
- FP – failure probability
- GEO – geostationary Earth orbit
- HST – Hubble Space Telescope
- JUNO – JUpiter Near-polar Orbiter
- LEO – low Earth orbit
- MMS – Magnetospheric MultiScale
- NOVICE – Numerical Optimizations, Visualizations and Integrations on Computer Aided Design (CAD)/Constructive Solid Geometry (CSG) Edifices
- PDF – probability density function
- RDM – radiation design margin
- TID – total ionizing dose
BACKUP SLIDES
Device Failure Distribution
HV801 Optocoupler
DDD Probability Distributions for 1 Year
10 – 1000 mils Aluminum

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