CONFIDENCE LEVEL BASED APPROACH TO TOTAL DOSE SPECIFICATION FOR SPACECRAFT ELECTRONICS

M.A. Xapsos\textsuperscript{1}, C. Stauffer\textsuperscript{2}, A. Phan\textsuperscript{2}, S.S. McClure\textsuperscript{3}, R.L. Ladbury\textsuperscript{1}, J.A. Pellish\textsuperscript{1}, M.J. Campola\textsuperscript{1} and K.A. LaBel\textsuperscript{1}

\textsuperscript{1}NASA Goddard Space Flight Center, Greenbelt, MD
\textsuperscript{2}AS&D, Inc., Greenbelt, MD
\textsuperscript{3}Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

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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

Credit: http://mms.gsfc.nasa.gov
Device Failure Distribution
SFT2907A Bipolar Transistors

10 V collector-emitter bias
1 mA collector current

Failure Level

DC Current Gain vs. Dose (krad-Si)
Cumulative Probability vs. Failure Dose (krad-Si)

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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

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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

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BACKUP SLIDES
Device Failure Distribution
HV801 Optocoupler
Failure Probabilities
HV801 Optocoupler

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

- \( H(x) = \) CDF for environment dose
- \( g(x) = \) PDF for device failure

Failure probability \((P_{\text{fail}})\) is the probability of a total dose failure during a mission.