Small Satellites Hardened by Design for the use of Non-Space Qualified EEE Parts

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Motivation

- Class C or D missions: medium or high risk
- Quality of parts is an important factor in the success of missions
- Most non-qualified parts are PEMs
Risk reduction strategy

- **Upscreening?**
  - Screening
  - Qualification tests

- **Hardening by Design?**
  - Protection from radiation and early wear out
  - Failure mitigation

- **Both?**
Up-screening - Is it enough?

<table>
<thead>
<tr>
<th>Part Designation</th>
<th>Use As Is</th>
<th>Screen To Requirements in Table 2</th>
<th>Qualify To Requirements in Table 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1:</strong></td>
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<tr>
<td>1) Class V or Class S</td>
<td>X</td>
<td>X 3/, 4/, 5/</td>
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<td>2) Class Q or Class B</td>
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<td>X 4/, 5/</td>
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<td>3) SCD</td>
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<td>4) 883-Compliant or Class M</td>
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<td><strong>Level 2:</strong></td>
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<td>1) Class V or Class S</td>
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<td>X 4/</td>
<td>X 9/</td>
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<td>X 4/, 8/</td>
<td>X 9/</td>
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<td>3) 883-Compliant or Class M</td>
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<td>5) Mfr. Hi-Rel 7/</td>
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<td>6) Commercial</td>
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- The more demanding environmental requirements
- The lower the size of the accepted batch; if any

Parts needs to be protected by design
Risk Reduction Strategy

- **Reduction of the Problem Dimensions**
  - Information Search
    - Heritage/Open Databases
  - Testing
    - Radiation tolerance/Reliability
  - Criticality Analysis (FMEA)

- **Protection**
  - Radiation hardening strategy
  - Optimized Thermal design
  - Derating

- **Mitigation**
  - Redundancy/FDIR
TID and DD mitigation

- Radiation shielding
  - Electrons and low energy protons
  - Satellite/Boxes level
    - Ray trace analysis
  - Spot shielding
    - Secondary radiation
- Derating
  - Design for degraded parameters ie: supply current
- Operating Temperature
  - Dark current increase in CCDs
SEE Mitigation: Destructive

- **SEL**
  - Current limiting with reset

- **SEB**
  - **Power MOSFETs**
    - Drain current limiting (protection)
    - Derating of Drain-Source Voltage (prevention)

- **SEGR**
  - **Power MOSFETs**
    - Using in a safe operating range
  - **Memory cells**
    - High purity oxides diminishes risk
SEE Mitigation: Non-Destructive

- **Service Loss**
  - SEU
    - Processors
      - Redundancy in time
      - Steplock
      - Watch dog
    - SET
      - Moderate clock speed
SEE Mitigation

- Data Quality Loss
  - SEU
    - Memories
      - Parity and CRC (error detection)
      - Hamming (single and double bit errors)
      - Reed Solomon (multiple-consecutive bits)
      - TMR
      - Scrubbing
Optimized Thermal Design

- **Wear out** activated by high semiconductor junction temperature:
  - Electromigration (Blacks equation)
  - Corrosion

- Mechanical **fatigue** depending on the range of thermal cycles (Coffin-Mason)
  - BGA and CCGA cases

- **Mitigation**: System level Thermal design
Redundancy Mitigation

- Although the reliability figure decreases because of **interconnections** when the granularity level at which the redundancy is applied is too fine.
- There is always an **optimum** value of reliability for granularity levels greater than one.
- Redundancy at **constellation and satellite level** is not always the best strategy.
Conclusions

- The use of non space-qualified electronic parts in space missions is becoming more and more frequent.
- They can be “use as is” only when high risk is tolerated.
- Up-screening of these parts is necessary for extending mission lifetime expectations.
- Special design practices are needed to guarantee the success of the up-screening processes.
Complementary slides
Latchup

**Temperature Dependence of Basic Parameters**

- $V_{BE}$ drops from 0.7 to 0.5V at 125°C
- Well resistance doubles at 125°C compared to room temperature

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**Saturation cross section increases with temperature**

**Threshold LET decreases with temperature**
Electromigration

Blacks Equation
Mathematical Model for Mean Time to Failure (MTTF)

\[ MTTF = \frac{A}{J^N} \cdot \exp\left(\frac{E_a}{kT}\right) \]

- \( A \): Cross-section-area-depdendant constant
- \( J \): Current Density
- \( N \): Scaling factor, usually set to 2
- \( E_a \): Activation energy for electromigration
- \( k \): Boltzmann constant
- \( T \): Temperature
Corrosion

- Electronic devices with aluminum or aluminum alloy with small percentages of copper and silicon metallization are subject to corrosion failures and therefore can be described with the following model:

\[ L(RH, V, T) = B_0 \exp\left[ (-\alpha)RH \right] f(V) \exp\left( \frac{E_a}{kT} \right) \]

- where:
  - \( B_0 \) is an arbitrary scale factor.
  - \( \alpha \) is equal to 0.1 to 0.15 per % RH.
  - \( f(V) \) is an unknown function of applied voltage, with empirical value of 0.12 to 0.15.
Mechanical Fatigue

Coffin-Manson

\[ \tau = A \times (\Delta T)^n, \]

\[ A_{F_{TC}} = (\Delta T_s/\Delta T_0)^n, \]