EEE COMPONENT ENGINEERING TRAINING

FOR

ENGINEERS AND PROCUREMENT PERSONNEL

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ESCC System Overview

Qualification of EEE Component for Space Applications

L. BONORA, ESA/ESTEC, 2007

SUMMARY

- The ESCC System Applicability & Objectives
- Overview of the relevant requirements
- ESCC Specification System
- ESCC Qualification
- Minimum Quality Management Requirements
- ESCC QPL - EPPL
• ESCC stands for European Space Components Coordination
• The ESCC System is applicable to:
  – EEE Components
    • Electronic → ICs (LSI, VLSI), transistors, diodes …
    • Electrical → resistors, capacitors, connectors, cables …
    • Electromechanical → relays, switches …
  – European Components (for Qualification)

• Main goal: To improve the availability of high reliability EEE components, with the required performance, for space programmes
• By means of:
  – An harmonisation of the resources
  – Development efforts in ESA Member states
  – An unified system for the standardisation, product specification, qualification and procurement of EEE components

ESCC Charter and procedures, see: https://spacecomponents.org
• The ESCC System Applicability & Objectives
• Overview of the relevant requirements
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• ESCC Qualification
• Minimum Quality Management Requirements
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RELEVANT REQUIREMENTS

• ECSS (standards) ➔ European Cooperation for Space Standardisation
  − Space Project Management; Space Product Assurance; Space Engineering

  *ECSS-Q60B: Requirements for selection, control, procurement and usage of EEE components at equipment level*

• ESCC (specifications)
  − The ESCC System is an international system for the specification, qualification and procurement of EEE components for use in Space programmes
  − The ESCC system exists to assure users that EEE components, manufactured and tested to ESCC requirements, will have the performance and reliability demanded by space applications.
ECSS- Q60B

- Non-qualified components have to be evaluated
- ECSS defines *what to do* but not *how to do*
- The evaluation programme shall include:
  - A constructional analysis
  - A manufacturer assessment
  - An evaluation testing programme
    - Electrical stress (Life test, HTRB ...)
    - Mechanical stress (shocks, vibrations ...)
    - Environmental stress (temp. shock and cycling, seal tests ...)
  - Assembly capability
  - Radiation testing (TID and SEE)
ESCC Specification System

The ESCC System is a self standing system which provides for:

- The technical specification of EEE parts
- Methodologies for component evaluation and qualification
- Outline of necessary test methods
- Quality Assurance requirements
- Operational provision

All ESCC Specifications are freely available from the ESCIES web site. The web address is https://escies.org

The ESCC SPECIFICATION SYSTEM

For users, 3 integrated levels of specifications

- Basic (L2): test methods, qualification methodologies and general requirements applicable to all ESCC components
- Generic (L3): requirements for screening, periodic or lot acceptance testing and qualification testing for individual families of components
- Detail (L4): performance requirements and procurement specification for individual or ranges of particular components (basically, they are comprehensive data sheets)

Detail Spec. shall be read in conjunction with the corresponding Generic Spec. and referenced Basic Spec.
The ESCC SPECIFICATION SYSTEM

• Coding of ESCC Basic Specifications:
  – General format:
    • 2 xx yy for self standing spec. or parent spec. supplemented by ancillary spec.
    • 2 xx zzzz for ancillary spec.
    • xx: coding of the subject matter
    • yy: serial number of the specification
    • zzzz: Generic code for the relevant family

• ESCC Basic Specifications – some examples:
  – General and quality requirements:
    • 21500: Calibration Syst. Req.
    • 24600: Minimum Qual. Syst. Req.
  – Qualification methodologies:
    • 20100: Qual. Of Standard Electronic Components
  – Test methods and technical requirements:
    • 20400: Internal Visual Inspection ( + 2043000 for Capacitors; 2049000 for ICs …)
    • 22900: TID Steady-State Irradiation Test Method
• Coding of ESCC Generic Specifications:
  – General format:
    • A unique 4 digit number, ranging 3000 to 9999.
    • Structured by family of components
    • Some examples:
      – 30xx Capacitors / 34xx Connectors / 36xx Relays / 39xx Cables…
      – 40xx Resistors – Thermistors – Heaters
      – 51xx Diodes / 52xx Transistors / 54xx Opto / 55xx µwave diodes..
      – 9xxx ICs / CCDs / MMICs

• Coding of ESCC Detail Specifications:
  – General format:
    • A unique 4 + 3 digit number, xxxx yyy.
    • xxxx: it indicates the associated Generic Spec.
    • yyy: Serial number of the Spec.
    • Example:
      – 3001/001: Capacitors Fixed Ceramic Dielectric Type I, based on type CLC904L
      – associated to the Generic Spec 3001
      – 3001: Generic Specification for Capacitors Fixed Ceramic Dielectric Types I and II

• All the ESCC Spec. are available on the ESCIES website and listed in the ESCC REP001 document
SUMMARY

• The ESCC System Applicability & Objectives
• Overview of the relevant requirements
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• ESCC Qualification
• Minimum Quality Management Requirements
• ESCC QPL - EPPL

ESCC QUALIFICATION

• ESCC qualification is a status given to electronic components which are manufactured under controlled conditions and which have been shown to meet all the requirements of the relevant ESCC specifications.
• 3 different but equivalent and similarly structured approaches are possible:
  – Component Qualification ⇒ for one EEE component type or a family
  – Capability Approval ⇒ customized or application specific components
  – Technology Flow Qual. ⇒ stable and reliable manufacturing technology flows
• Irrespective of the selected qualification approach and unlike the US MIL System, ESCC is based on a 2 step qualification approach: Evaluation + Qualification
ESCC QUALIFICATION

• Evaluation
  ● During the Evaluation phase, components/technologies can be extensively characterised and margins determined
    – Manufacturer Evaluation (ESCC 20200) -> AUDIT
    – Component / Technology Evaluation (ESCC 22600 and ancillaries)
      - Preparation and ESCC approval of an Evaluation Test Program (ETP)
      - Preparation of a Process Identification Document (PID)
      - Preparation of a draft Detail Specification (if not already existing)

• Qualification (following a successful Evaluation)
  – Component Qualification Testing
    - On components produced strictly as defined in the final PID and from a given lot (actually, the first production lot)
    - According to ESCC Generic Spec. requirements

ESCC 20200
(Comp. Manuf. Eval.)

EVALUATION OF THE MANUFACTURER
(Quality Management System and Line Audit)

• A full on-site audit is required to validate:
  – The overall manufacturing facility, its organisation and management, the Quality Management System
  – The manufacturing line and applied controls/inspections

• The manufacturer is required to give a satisfactory demonstration of the organisation and management applicable, at least to:
  – the quality management system and documentation
  – management of non-conformances
  – management of sub-contractors and suppliers
  – incoming and storage of raw material and piece parts, related controls
  – maintenance and calibration
  – production line and associated inspections
  – traceability

ESA/ESTEC
TEC-QS
COMPONENT EVALUATION

- **Constructional Analysis**
  - On random samples taken from the current production
  - Performed by the Evaluation Authority (ESCC Executive)

- **Evaluation Test Programme**
  - Established in conjunction with the Manufacturer / ESCC Executive
  - On a sample (~ 100 parts) representative of the component family
  - In order to determine failure modes and margins, it includes:
    - Endurance tests (HTRB, Extended Burn-in, Life Test in stringent conditions …)
    - Destructive tests (Step-stress, radiation, Environmental/Mechanical/Assembly…)
  - Includes a DPA on representative components
  - Ancillary specifications 226xxxx* describe the procedure and requirements to create and perform an ETP

  *: xxxx = generic spec. number

COMPONENT EVALUATION

- **Process Identification Document (PID)**
  - Shall be prepared by the Manufacturer
  - Establishes a precise reference for an electronic component qualified in accordance with the ESCC System
    - Component's design configuration
    - Materials used in manufacture
    - Manufacturing processes and controls
    - Inspections and tests to be carried out during and after manufacture
  - PID shall be in accordance with the requirements of **ESCC 22700**

- **Detail Specification**
  - Necessary if not already described by an existing Detail Specification
  - Or if the existing specification requires updating
  - Described in **ESCC 20800**.
Typical ETP for silicon ICs
(ESCC 2269000)

INITIAL MEASUREMENTS – 100% read and records

DESTRUCTIVE TESTS – # 50 parts

STEP-STRESS – Temp & Power Radiation (TID / SEE / DD)
CA
PACKAGE (Thermal & Mechanical)
ELECTRICAL (ESD, SDA, Current limits …)

ENDURANCE TESTS – # 40 parts

HTRB
ACCELERATED ELECT. ENDURANCE
EXTENDED BURN-IN

CONTROL & RESERVE – # 10 parts

Typical ETP for fixed capacitors
(ESCC 2263000)

INITIAL MEASUREMENTS – 100% read and records

DESTRUCTIVE TESTS – # 50 parts

THERMAL SHOCK
CA

STEP STRESS (Voltage, Temp. Torque (if screws))
MECHANICAL (Acc. Damp Heat, Robustness of terminations, seal test, solderability …)

ESD TESTING – # 10 parts

STEADY STATE ACC. LIFE – # 45 parts

CONTROL & RESERVE – # 10 parts
QUALIFICATION TESTING PHASE

- Prerequisites:
  - Successful completion of the Evaluation Phase (proposal for EPPL listing)
  - The PID reviewed and approved by ESCC Executive
  - A production and test schedule for major processing operations
  - A Production Flow Chart, Process Schedules and Inspection Procedures

- Components required for qualification testing must be produced strictly in accordance with the PID (first normal production lot)
- Qualification testing of the component must be in accordance with the requirements of the relevant ESCC Generic Specification
- On successful completion of the testing phase => ESCC QPL
- A Qualification, once established, is valid for 2 years

QUALITY CONFORMANCE DOCUMENTATION AND REQUIREMENTS

- Certificate of Conformity
- Records: Manufacturers have to maintain
  - detailed records of each production lot of a qualified component and/or test structure (5 years, possibly 10 years in the future)
  - detailed records of all qualified components found to be defective

- ESA Logo
  - Only components procured from a qualified source, whose qualification status is valid at the time of delivery, are marked with the ESA logo
  - Any components, either from a qualified source or not, which fail to meet an inspection or test requirements, or are non-conforming in any manner to the ESCC requirements:
    - must not be marked with ESCC marking
    - must have the marking removed or permanently obliterated
GENERAL FLOW FOR ESCC PARTS

PRODUCTION CONTROL
(In-process & final controls)

SCREENING

QUALIFICATION or
LOT VALIDATION TESTING

RELEASE

QUALIFICATION
MAINTENANCE

DELIVERY

ESAC/ESTEC
TEC/QS

SCREENING TESTS / COMPONENTS FROM PRODUCTION CONTROL (F3)

All components shall be SERIALISED prior screening tests

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Spec No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Temp. Stabilisation Bake</td>
<td>883-TM1058</td>
</tr>
<tr>
<td>Temp. Cycling</td>
<td>883-TM1010C</td>
</tr>
<tr>
<td>PIND</td>
<td>883-TM3000A</td>
</tr>
<tr>
<td>Param. Drift Values (Initial Measurement)</td>
<td></td>
</tr>
<tr>
<td>High Temp., Reverse Bias, BI</td>
<td>883-TM1015A</td>
</tr>
<tr>
<td>Power BI post HTBB and before Power BI</td>
<td></td>
</tr>
<tr>
<td>Final PIV</td>
<td>883-TM1015 B/Bor E</td>
</tr>
<tr>
<td>3 0 High and Low Temp. Elec. Measurements</td>
<td>ESCC DS</td>
</tr>
<tr>
<td>Room Temp. Elec. Measurements</td>
<td>ESCC DS</td>
</tr>
<tr>
<td>Check for LOT FAILURE</td>
<td></td>
</tr>
<tr>
<td>Solderability</td>
<td></td>
</tr>
<tr>
<td>PDV if applicable</td>
<td></td>
</tr>
</tbody>
</table>

ESAC/ESTEC
TEC/QS
### Qualification and Periodic Tests (F4)

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>SG1 Endurance SG</th>
<th>SG2 Assembly SG</th>
<th>SG3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 months period</td>
<td>12 months period</td>
<td>24 months period</td>
</tr>
<tr>
<td>Mech. Shock</td>
<td>883-20008</td>
<td>883-1011C</td>
<td></td>
</tr>
<tr>
<td>Therm. Shock</td>
<td>883-2007A</td>
<td>883-1004</td>
<td></td>
</tr>
<tr>
<td>Vibration</td>
<td>883-20007A</td>
<td>883-1004</td>
<td>Electrical Measurements</td>
</tr>
<tr>
<td>Constant Acc.</td>
<td>883-2007E</td>
<td>883-1014A/B/C</td>
<td>Bond Strength</td>
</tr>
<tr>
<td>Seals</td>
<td>883-1014A/B/C</td>
<td>883-1014A/B/C</td>
<td>Die Shear</td>
</tr>
<tr>
<td>Electrical Measurements</td>
<td>Electrical Measurements</td>
<td>Electrical Measurements</td>
<td>Electrical Measurements</td>
</tr>
</tbody>
</table>

**TESTS:**
- Mech. Shock
- Therm. Shock
- Operating Life Test 2000h
- Terminal Strength
- Vibration
- Electrical Measurements
- Internal Visual Inspection
- ESCC 20400
- Bond Strength
- Die Shear
- ESCC 20500

**COMPONENTS:**
- 883-1014A/B/C
- 883-1014A/B/C

### The ESCC System Applicability & Objectives
- Overview of the relevant requirements
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• As a minimum, the Manufacturer quality management plan must address the ESCC 24600 requirements (prescriptions to ISO 9001:2000).
• The resulting Manufacturer quality management system has to include and demonstrate the application of all the applicable ESCC 24600 requirements.

• An appointed CHIEF INSPECTOR with clearly defined authority and responsibility as the ESCC point of contact
• CONTROL of NON-CONFORMING PRODUCTS invoking the requirements of ESCC 22800
• QUALITY and CONTROL DOCUMENTATION including:
  – Quality manual (indicating as an objective the conformance to ESCC 24600)
  – Document control procedures for all documents related to the ESCC components manufacture (incl. subs./suppliers management)
  – A maintained PID
  – Change Control Programme establishing the requirement for documentation of ALL changes, their reasons and the associated data including reliability and re-qualification results
QUALITY CONFORMANCE DOCUMENTATION AND REQUIREMENTS

• TRACEABILITY has to be maintained at all stages of production and tests for all lots
  – Quality records have to be maintained for 5 years (possibly 10 in a near future)
  – Record of all components found to be defective
• A Conversion of CUSTOMER REQUIREMENTS (specific tests or test vehicles, marking, rework, screening)
• A CONTROL/INSPECTION prog. Including:
  – On-receipt / incoming tests / inspections
  – Applicable ESCC in-process monitoring/control and back-end tests
  – Procedures shall detail the frequency, methods and criteria for evaluating test results
  – Data shall be maintained

A training and certification programme with periodic recertification (for operators involved in ESCC components manufacture)
• An appropriate failure analysis capability has to be established with documented procedures for the application of the techniques and the generation of reports. This capability may include the use of appropriate external facilities.
• A Calibration programme to meet ESCC 21500
• The ESCC System Applicability & Objectives
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ESCC QPL - EPPL

• ESCC QPL:
The ESCC Executive publishes a list of components and technologies which have been, respectively, qualified and capability approved to the rules of the ESCC Specification System and the results certified by ESA.

These components and technologies are intended for use in ESA and other European spacecraft and Space segment hardware in accordance with the requirements defined in the ECSS Standard, ECSS-Q-60, Space Product Assurance - Electrical, Electronic and Electromechanical (EEE) Components.
EPPL:
The EPPL is a list of preferred and suitable components to be used by European manufacturers of spacecraft hardware and associated equipment and covering all design applications.

The EPPL is made up of two parts:
- Part 1: Components which are fully qualified or evaluated to recognised space standards giving full confidence for space usage.
- Part 2: Components for which the potential capability to satisfy space application requirements has been demonstrated but which have not yet reached the level of full confidence.

The EPPL is NOT a list of qualified components even if ESCC qualified components are included.
SUMMARY

- DSCC
- MIL System and Documentation
  - Handbooks MIL-HDBK
  - Generic Specifications MIL-M / PRF
  - Detail Specifications
  - Standards MIL-STD
- Conclusion
What is DSCC?

- Defense Supply Center – Columbus  
  www.dscc.dla.mil
- Part of the DoD
- Roles:
  - Standardization and procurement of military parts for US armed forces and also NASA
  - MIL system documentation management
  - Manufacturer audits and US QML/QPL management

  The MIL system covers both Space and Military quality levels

SUMMARY

- DSCC
- MIL System and Documentation
  - Handbooks MIL-HDBK
  - Generic Specifications MIL-M / PRF
  - Detail Specifications
  - Standards MIL-STD
- Conclusion
MILITARY HANDBOOKS
MIL-HDBK

• General information & guidance
• Not requirements
• Examples:
  – MIL-HDBK-103: List of Standard Microcircuit Drawings
  – MIL-HDBK-512: Parts Management

SUMMARY

• DSCC
• MIL System and Documentation
  – Handbooks MIL-HDBK
  – Generic Specifications MIL-M / PRF
  – Detail Specifications
  – Standards MIL-STD
• Conclusion
MILITARY SPECIFICATIONS
MIL-PRF and older MIL-M/C...

- General Specifications applicable to component families
- They Outline all the procedures necessary for parts and manufacturers to be included in US gov. endorsed lists (e.g., US QML)
- Examples (active components):
  - ICs: MIL-PRF-38535
    (gradually replaces the MIL-M-38510)
  - Discrete Comp.: MIL-PRF-19500
  - Hybrids: MIL-PRF-38534

### Active Components

<table>
<thead>
<tr>
<th>Reliability Level</th>
<th>SPACE</th>
<th>MILITARY</th>
<th>883B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated Circuits</td>
<td>QML V</td>
<td>QML Q</td>
<td>Class M</td>
</tr>
<tr>
<td>MIL-PRF-38535</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formerly Class S in M-38510</td>
<td></td>
<td>Formerly Class B in M-38510</td>
<td>Not Qualified and not QML listed</td>
</tr>
<tr>
<td>Still associated with class S in MIL-STD-883</td>
<td></td>
<td>Still associated with class B in MIL-STD-883</td>
<td></td>
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<tr>
<td>Discrete MIL-PRF-19500</td>
<td>JAN S</td>
<td>JAN TXV</td>
<td>JANTX</td>
</tr>
<tr>
<td>Hybrids</td>
<td>Class K</td>
<td>Class H</td>
<td></td>
</tr>
<tr>
<td>MIL-PRF-38534</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Some elements of comparison between levels for ICs 1/2

<table>
<thead>
<tr>
<th></th>
<th>QML V / JAN S</th>
<th>QML Q / JANTXV</th>
<th>883B QML M JANTX</th>
<th>Commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Microcircuit Process Wafer Fabrication</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agency Certification of Plant and Operators</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Baseline Process Flow (Agency Control)</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Traceability of Baseline Changes</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
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<tr>
<td>Number of Wafer Runs in lot</td>
<td>1</td>
<td></td>
<td>Not controlled (but only from certified lab)</td>
<td>N</td>
</tr>
<tr>
<td>Wafer Lot Acceptance</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Wafer Rework Control</td>
<td>Y</td>
<td>Y</td>
<td>Not controlled</td>
<td>Not controlled</td>
</tr>
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### Assembly

<table>
<thead>
<tr>
<th></th>
<th>QML V / JAN S</th>
<th>QML Q / JANTXV</th>
<th>883B QML M JANTX</th>
<th>Commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agency Certification of Plant and Operators</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Internal Visual Inspection</td>
<td>Y cond. A</td>
<td>Y cond. B</td>
<td>N+Mil Spec, Y+Vendor Spec</td>
<td>N</td>
</tr>
<tr>
<td>Tightened Lot Formation: Wafer runs</td>
<td>1</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Destructive Die Shear monitor</td>
<td>2h</td>
<td>4h</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Destructive Bond Pull monitor</td>
<td>2h</td>
<td>4h</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Precap Visual Inspection</td>
<td>100%</td>
<td>15 piece sample</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Non-destructive Bond Pull</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
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<tr>
<td>Hermeticity</td>
<td>100%</td>
<td>100%</td>
<td>N</td>
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### Screening

<table>
<thead>
<tr>
<th></th>
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<th>QML Q / JANTXV</th>
<th>883B QML M JANTX</th>
<th>Commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agency Certification of Plant and Operators</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Electrical subgroup 1-12 tested</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Extended Burns-In (dynamic, 240h)</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>100% PIND test</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>PDA</td>
<td>5%</td>
<td>10%</td>
<td>some</td>
<td>N</td>
</tr>
<tr>
<td>Attributes data</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Variable data</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Hermeticity at End-Of-Line</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>X rays</td>
<td>100%</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Failure Analysis Requirements</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
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</table>

### Qualification

<table>
<thead>
<tr>
<th></th>
<th>QML V / JAN S</th>
<th>QML Q / JANTXV</th>
<th>883B QML M JANTX</th>
<th>Commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agency Certification of Plant and Operators</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Frequency of 1000h Life test</td>
<td>every lot</td>
<td>12 months</td>
<td>12 months</td>
<td>N</td>
</tr>
<tr>
<td>Freq. Of Package Qual.</td>
<td>6-12 months</td>
<td>12 months</td>
<td>12 months</td>
<td>N</td>
</tr>
</tbody>
</table>

---

23
Numerous MIL Specifications are available for passive components (-PRF/-M/-C/-DTL...)

Quality level concept different from active parts:
- Based on life tests (cumulative test results) to determine Failure Rate Levels (FRL) → “Established Reliability”
- 2 different statistic laws but providing consistent results
  - Exponential Distribution (EFRL)
  - Weibull Distribution (WFRL) – mainly for capacitors
- Unit: % of failures per 1000 hours
- MIL-STD-690: Failure Rate Sampling Plans and Procedures (qual. and lot conformance inspections)

<table>
<thead>
<tr>
<th>Failure rate: % / 1000h</th>
<th>EFRL</th>
<th>WRFL</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0001</td>
<td>N/A</td>
<td>E</td>
</tr>
<tr>
<td>0.001</td>
<td>S</td>
<td>D</td>
</tr>
<tr>
<td>0.01</td>
<td>R</td>
<td>C</td>
</tr>
<tr>
<td>0.1</td>
<td>P</td>
<td>B</td>
</tr>
<tr>
<td>1</td>
<td>M</td>
<td>N/A</td>
</tr>
</tbody>
</table>

If parts are not produced following an ER programme, they receive a specific code detailed in the relevant MIL Specification
SUMMARY

• DSCC
• MIL System and Documentation
  – Handbooks MIL-HDBK
  – Generic Specifications MIL-M / PRF
  – Detail Specifications
  – Standards MIL-STD
• Conclusion

DETAIL SPECIFICATIONS

• Subordinated to Generic Specifications
• ICs
  – Standard Microcircuit Drawing: SMD-xxxxx
  – MIL-HDBK-103: List of Standard Microcircuit Drawings
  – Former System: MIL-M-38510/xxx (slash sheets)
• Discrete Components
  – MIL-PRF-19500/xxx
• Passive Components
  – MIL-PRF-xxxxx/yyy (xxxxx: related Generic Specification)
SUMMARY

• DSCC
• MIL System and Documentation
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• Conclusion

MILITARY STANDARDS
MIL-STD

• Test methods for Qualification and Screening
  – MIL-STD-690: Failure Rate Sampling Plans and Procedures

To be read in conjunction with a MIL Specification
- STD 750 ↔ PRF 19500
- STD 883 ↔ PRF 38535
• List of Test Methods (TMs) and Procedures
• TMs are organised by purpose:
  – 1000 Series → Environmental Tests
    • 1010: temperature cycling; 1019: TID …
  – 2000 Series → Mechanical Tests
    • 2001: constant acceleration; 2011: bond strength …
  – 3000 Series → Electrical Tests (Digital)
    • 3006: $V_{OH}$; 3009: $V_{IL}$ …
  – 4000 Series → Electrical Tests (Linear)
    • 4001: Input offset voltage and current, bias current …

• 5000 Series: Dedicated to Test Procedures
  – 5004 Screening
  – 5005 Qualification and Quality Conformance
  – 5007 Wafer Lot Acceptance
  – 5008 Hybrid and Multichip Microcircuits
  – 5010 Custom Monolithic Microcircuits
  – 5012 Fault Coverage Measurement (digital)
  – 5013 GaAs Wafers Production Control and Acceptance
MIL-STD-883
Test Method Standard - Microcircuits

• 5000 Series: Dedicated to Test Procedures
  – 5004 Screening
  – 5005 Qualification and Quality Conformance
  – 5007 Wafer Lot Acceptance
  – 5008 Hybrid and Multichip Microcircuits
  – 5010 Custom Monolithic Microcircuits
  – 5012 Fault Coverage Measurement (digital)
  – 5013 GaAs Wafers Production Control and Acceptance

MIL-STD-883
Method 5004

• 5004 SCREENING
• Requirements associated with 2 Class levels:
  B: Military / S: Space
• Each Class Level provides:
  – A list of tests to be performed
  – The related TM and test condition(s)
  – The requirements (sample size, acceptance criteria …)
### MIL-STD-883 / Method 5004

<table>
<thead>
<tr>
<th>Screen</th>
<th>Method</th>
<th>Class level I</th>
<th>Class level II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water for acceptance</td>
<td>5007</td>
<td>All Lots</td>
<td>N/A</td>
</tr>
<tr>
<td>Residual dielectric bond pull</td>
<td>5025</td>
<td>100%</td>
<td>N/A</td>
</tr>
<tr>
<td>Internal visual</td>
<td>2010</td>
<td>Condition A</td>
<td>Condition B</td>
</tr>
<tr>
<td>Temperature cycling</td>
<td>2010</td>
<td>Condition C</td>
<td>Condition D</td>
</tr>
<tr>
<td>Constant acceleration</td>
<td>2001</td>
<td>Condition E or Y1 Only</td>
<td>Condition E or Y1 Only</td>
</tr>
<tr>
<td>Visual inspection</td>
<td>2000</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Particle induced noise detection (PIN)</td>
<td>2000</td>
<td>Condition A</td>
<td>N/A</td>
</tr>
<tr>
<td>Sensitization</td>
<td>2000</td>
<td>100%</td>
<td>N/A</td>
</tr>
<tr>
<td>Pre burn-in electrical parameters</td>
<td>2015</td>
<td>In accordance with applicable specification</td>
<td>N/A</td>
</tr>
<tr>
<td>Burn-in test</td>
<td>1015</td>
<td>240 hours at 125°C minimum</td>
<td>160 hours at 125°C minimum</td>
</tr>
<tr>
<td>Interim (post burn-in) electrical parameters</td>
<td>1015</td>
<td>In accordance with applicable specification</td>
<td>In accordance with applicable specification</td>
</tr>
<tr>
<td>Reverse bias burn-in</td>
<td>1015</td>
<td>Condition A or C, 48 hours at 150°C minimum</td>
<td>N/A</td>
</tr>
<tr>
<td>Percent defective allowable (PDA) calculation</td>
<td>1015</td>
<td>4 percent or 5 percent, functional parameters at 25°C</td>
<td>5 percent</td>
</tr>
<tr>
<td>Final electrical test</td>
<td></td>
<td>In accordance with applicable specification</td>
<td>In accordance with applicable specification</td>
</tr>
<tr>
<td>Static tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) 25°C (subgroup 1, table I, 5005)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) Maximum and minimum rated operating temperature (subgroups 2, 3, table I, 5005)</td>
<td>1014</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Dynamic or functional tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) 25°C (subgroup 4, 5, 6, or 7, table I, method 5005) Minimum and maximum rated operating temperature (subgroups 5 and 6, or if table I, method 5005)</td>
<td>1015</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>2) Switching tests at 25°C</td>
<td>1014</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Radiographic</td>
<td>2012</td>
<td>Two views</td>
<td>N/A</td>
</tr>
<tr>
<td>Qualification or quality conformance inspection test sample selection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External visual</td>
<td>2000</td>
<td>100% or 1,160</td>
<td>100% or 1,160</td>
</tr>
<tr>
<td>Radiation latch-up</td>
<td>2000</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

### MIL-STD-883

**Method 5005**

- **5005 Qualification and Quality Conformance Procedures**
- **Details the requirements for:**
  - Qualification
  - Requalification (major process change)
  - Maintenance of Qualification
    - QCI → Quality Conformance Inspections
- **2 Class Levels (B/S) as in Method 5004**
MIL-STD-883 / Method 5005

• 5 groups of tests
  – A: Class B & S - Table I - Electrical
  – B: Class S - Table IIa – Package and Life Test
    Class B – Table IIb - Package
  – C: Class B – table III – Life Test
  – D: Class B & S – table IV – Package and Environmental
  – E: Radiation Hardness Assurance

QCI: - Groups A & B on every production lot (by sampling)
- Group C & D, periodic testing
MIL-STD-202
ELECTRONIC AND ELECTRICAL COMPONENT PARTS
(PASSIVE COMPONENTS)

• List of Test Methods (TMs) only
• TMs are organised by purpose:
  – 100 Class → Environmental Tests
    • 101: salt atmosphere; 103: humidity …
  – 200 Class → Physical Characteristics
    • 201: vibration; 210: resistance to soldering heat…
  – 300 Class → Electrical Characteristics
    • 301: dielectric breakdown voltage; 302: insulation resistance …

SUMMARY

• DSCC
• MIL System and Documentation
  – Handbooks MIL-HDBK
  – Generic Specifications MIL-M / PRF
  – Detail Specifications
  – Standards MIL-STD
• Conclusion
CONCLUSION

• 2 systems in parallel
  – QPL: Historically the first, part by part qualification (passive parts are still QPL listed).
  – QML: process oriented, line/technology qualification
    • Used for 3 families so far, ICs (PRF-38535), Hybrids (PRF-38534) and Discrete Comp. (PRF-19500)
  – Lists to be merged under the QPD (Qualified Products Database)

CONCLUSION

• The MIL system is widely used for selection and procurement of parts for space applications
• Standards such as STD-883 and STD-750 are reference documents used in ESCC Specifications
• A direct comparison of US and European normative systems is nonetheless uneasy due to the large variety of elements to be considered
• QML philosophy allows a larger flexibility to the qualified manufacturers, in terms of decision and management of process and control level changes, through their TRBs.
  ➤ Problem: Traceability to process changes or test modifications (suppression or reduction) is not always clearly visible/maintained.
Space Component Engineering

John Hopkins
Component Engineering Section

Contents of Presentation

• Introduction
• The space product life cycle
• The role of the component engineer
• Why we need them
• What component engineering does
• Alerts
• Derating
• Waivers
• Some Current Quality-related Issues
• Dos and donts
• Conclusion
Component Engineering Resources

- ECSS-Q60 Family of components:
- ECSS-Q30 Family of Standards
- ECSS-Q70 Series of standards
- On Line resources reside in https://escies.org
- ESA Preferred Parts List (EPPL)
- ESA Qualified parts list (QPL)
- NASA preferred parts selection list (NPSL)
- Mil Specs and Standards www.dscc.dla.mil

Space System Life Cycle (ECSS M30A)

- Propose Mission
- Define Mission
- Study SC Options
- Design Equipment
- Build Equipment
- Launch Spacecraft
- Clarify Mission
- Identify SC Options
- Decompose System
- Build, Test Models
- Test Equipment
- Operate Spacecraft
- Select Mission
- Specify Equipment
- Qualify Equipment
- Assemble Spacecraft
- Disseminate Data
- Test Spacecraft
- Pre-A, A, B, C, D, E
### Assurance Activities

<table>
<thead>
<tr>
<th>Phase</th>
<th>Organisation Related</th>
<th>Process Related</th>
<th>Product Related</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, B</td>
<td>Assess Plans &amp; Capabilities</td>
<td>Qualify Technologies</td>
<td>Review requirements &amp; System Design</td>
</tr>
<tr>
<td>C</td>
<td>Assess Readiness to Manufacture</td>
<td>Ensure suitable methods applied</td>
<td>Assure design suitability</td>
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<td>D</td>
<td>Assess Operation Readiness</td>
<td>Manufacturing Control</td>
<td>Verification Control</td>
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<tr>
<td>E</td>
<td></td>
<td>Ensure approved plans implemented</td>
<td>Manage problems &amp; Give feedback</td>
</tr>
</tbody>
</table>

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Component Engineering
Phase A & B Assurance Activities
Organisation Related – Assess Plans & Capabilities

Prepare PA Requirements
Check Standards Applied
- ECSS / ESCC
- ISO
- EN
- National
- Industry

Organisation Structure
- Completeness
- Clear responsibilities
- Lines of authority / reporting
- Technical capabilities
- Risk identification / control
- LLI!

Organisation Audits

ESA Project Plan
Contract
Project Proposal (Prime)
Industrial Consortium

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Component Engineering

Phase A & B Assurance Activities
Process Related – Qualify Technologies

Traceability
- Design
- Manufacturing Processes
- Prototype to Flight Config.

Validity of Verification
Discrepancy Control

Technology Needs
Design Item
Build Prototype
Assess Results
Evaluate Prototype
Technology Development

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Phase A & B Assurance Activities
Product Related – Review Requirements

- Traceability
  - Compliance to Requirements
  - Trade-off studies
  - Initial Dependability Assessment
  - Initial Safety Assessment
  - Selection of configured items
  - Management of Technical Risks
  - PDR at end of phase B

Assurance Activities

<table>
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</table>

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Phase C Assurance Activities
Process Related – Assure Implementation of Plans

Validation through inspection, and documentation

Audits
Inspections
Parts Control Boards
Project reviews
PADS

Phase C Assurance Activities
Product Related – Assure Design Suitability

Qualification Status
Product Design Definition
Manufacturing & Verification Documentation

Traceability
Approval Status
Verification Method

Design Analyses / Validation
Dependability Analyses
Safety Assessment
Component Assessments
Material / Process Review

Phase D Certificate of Qualification
# Assurance Activities

## Phase D Assurance Activities
**Process Related – Manufacturing Control**

<table>
<thead>
<tr>
<th>Traceability</th>
<th>Approval Status</th>
<th>Implementation Status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>• Audits</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Activity Reviews</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Manuf. Readiness</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inspections</th>
<th></th>
<th>Product Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Key Inspection</td>
<td></td>
<td>Process Specifications</td>
</tr>
<tr>
<td>• Mandatory Inspection</td>
<td></td>
<td>Procedures</td>
</tr>
</tbody>
</table>

| Nonconformance Control | |
|-------------------------| |
| End Item Data Package   | Certificate of Conformance |

## Phase Organisation

<table>
<thead>
<tr>
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<td>Ensure approved plans implemented</td>
<td></td>
<td>Manage problems &amp; Give feedback</td>
</tr>
</tbody>
</table>
Phase D Assurance Activities
Product Related – Verification Control

- Traceability
- Approval Status
- Test Reviews
  - Test Readiness Rev.
  - Post Test Review
  - Test Review Board
- Nonconformance Control
- Verification Status
  - VCD
- Acceptance
  - Configuration Audit
  - Delivery reviews

Test Plans
Test Specifications
Test Procedures
Test Reports
End Item Data Package
Qualification completed
Certificate of Acceptance

Assurance Activities

<table>
<thead>
<tr>
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<th>Product Related</th>
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<td></td>
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<td>Manage problems &amp; Give feedback</td>
</tr>
</tbody>
</table>

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Components Division

Phase E Assurance Activities
Process Related – Assurance of Activities

Approval Status
Activity Verification
  • Audits
  • Activity Reviews
Inspections
  • Key Inspection
  • Mandatory Inspection
Nonconformance Control

Product
Procedures
Plans
Activity Reports

Phases E Assurance Activities
Product Related: Problem Management & Feedback

- Anomaly Report
- Analyse Anomaly
- Identify Actions
- Implement Actions
- Verify Completion
- Close Report
- Maintain Database

- Design Guides
- Standards
- Reports
- Instructions

- Spacecraft Configuration
- Ground Segment Config.
- Procedures
- Data Recovery

Anomaly Occurs
Safeguard Spacecraft

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Component Engineering
### ESCC Specification system a recap

- **Generic Specifications**
  - Details as children
- **Basic specifications**
### The role of the engineer

To support their project covering the full product cycle:
- **Design for procurement and manufacture,**
- **Assure component choice that meets reliability requirements,**
- **Meet mission requirements**

---

### Components Division

ESCC GS 9000 – CHART F4

QUALIFICATION AND PERIODIC TESTS (F4)

(previous SCC Chart IV and V)

<table>
<thead>
<tr>
<th>SI</th>
<th>ENV./MECH. Subgroup</th>
<th>ENDURANCE SG</th>
<th>ASSEMBLY SG</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24 months period</td>
<td>12 months period</td>
<td>24 months period</td>
</tr>
<tr>
<td>2</td>
<td>90/10/8 components</td>
<td>90/10/8 components</td>
<td>90/10/8 components</td>
</tr>
</tbody>
</table>

- **Vibration**
  - 883-2007A
  - 883-1004
  - Electrical Measurements
    - Internal Visual Inspection
      - ESCC 20400

- **Shock**
  - 883-1011C
  - Operating Life Test 2000h
  - Terminal Strength
    - 883-2004

- **Moisture**
  - 883-2002B
  - 883-1011C
  - Electrical Measurements
    - (values recorded against SN)

- **Permanence of Marking**
  - ESCC 24800

- **Terminal Strength**
  - 883-2004
  - 883-1011

- **Die Shear**
  - 883-2019
  - 883-2017

- **Operating Life Test 2000h**
  - ESCC GS 9000
  - CHART F4

---

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**ESASME Course**

Component Engineering
Why Have Component Engineers?

- Space systems and safety requirements are complex
- Seldom generic requirements
- Demanding constraints: Mass, power, environment
- Large financial investments
- Safety and reliability are issue
- Long in-orbit life-times: up to 15 years or more
- Pressure to use continually advancing technology
  - without a full understanding of the item and failure mechanisms
  - Complex procurements-understand what you have got
- Continual pressures to reduce costs and development times

Why Have Component Engineering
Prevention is Better than Cure

- At the bid ensure that the correct quality levels are chosen cost and schedule impact
- Manage design teams to select approved components and manage the risks of non qualified parts.
- Define the optimum and safest usage
- Quality cost and schedule management of procurements
- Component use management-build and test
- Act as customer interface on EEE issues
- Support in orbit performance
  RISK MANAGEMENT THROUGH A DEFINED PROCESS
**What the Component Engineer Does**

- **Design Support:**
  - Ensure that the components chosen are preferred
  - Avoid use of problematic devices (analysis and awareness of alerts)
  - Work with the designer and the manufacturing engineer to define the risks of component use, assembly processes
  - Component Requirements Knowledge – in house and customer requirements
  - Hybridisation or PCB, packaging COB?
  - ASIC vs FPGA?
  - Project Preferred Parts List E-BOM prepared.
Component Engineering and Design Assurance

- Identify the components that are qualified
- Assess the components that are not qualified
- Radiation assessment and verification
- Support the Parts Stress Analysis, Worst case analysis and derating analysis.
- Prepare waivers / deviations for non compliant devices
  - Technical justification and consequences need understanding.
- PDR and CDR ensure that the DCL is correct and that all PADS are configured and approved correctly.

Derating ECSS Q30-11

- Derating is the intentional reduction in a parameter rating of a component in order to increase its useful life in terms of drift and reliability
- Covers, electrical parameters and thermal parameters
- Derating against a standard or from evaluation test results.
- Outside of agreed parameters is a deviation.
The Procurement Process:

DM and EM/ EQM:

Components need not be full flight – component engineer needs to ensure that device technology is appropriate - try to be representative.

EQM need not be fully flight screened but must come from the same line! But if a failure may have cost implication to project!

FM – fully compliant ESCC or Mil S level or equivalent

---

Procurement Process
The Optional Scenario:

IF you’re very small SME or you have issues on MOQ:
Will have storage issues
Will need competence for inspection
Will need competence for electrical test
Will need competence for physical analysis
Will need competence for design/use/failure analysis
Will need systems to manage alerts and configuration
Procurement process
The Optional Scenario

- Component Engineering competence is needed
- Reduce Infrastructure needs by buying in expertise
- There is the CPPA
  - Companies such as IGG, Technologica, Hirex, Toprel (all four are now ALTA), Spur, Tesat and Astrium Velizy.
  - Have labs, engineering and procurement capabilities as well as environmentally controlled stores.

It will cost money but may get an economy of scale if many procurements
ESA often do a CPPA procurement.

Procurement Process
Requirements

1. Must have a component list based on BOM and must fulfil the program requirements.
2. Procurement Specification preparation
   (Screening, lot acceptance or QCI, qualification )
3. PAD approved, justification of use, inspection stages, precap, buy off, data review, DPA needed.
4. Purchase order requirements defined
5. Inspection performance
6. Goods Received
Role of the DCL and Component type Reduction
Preferred versus Qualified

- Part Type reduction can be performed by using Qualified and or preferred parts.
- ESA has a qualified parts list: ESCC
- Also Preferred parts list (prime also have one of these) ESCC
- Qualified does Not mean Preferred!!
- What does qualified mean: it means test data available and procurement risk is minimum no DPA needed and LAT data often not required.
- Preferred Parts List is split in two:
  - Part 1 means: low risk- data available and procured regularly- often is a precursor to qualification.
  - Part 2 less data- buyers must mitigate their own risk, some heritage / procurement history.

Declared Components List

- Lay out defined in ECSS Q60
- Each line should refer to a used component is design.
- Component type, specification, manufacturer, procurement reference and PAD reference are all required.
- Brings together the Bills of materials, the PADs etc.
The PAD Process
Needs and Requirements

• Use of PAD is a summary of the component procurement needs:
  – Contains references to components specifications
  – Defines the route in to your company
  – Provides the user assurance that you are going to control the procurements
• ECSS Q60B example of PAD

PAD Contents

• Doc No: Unique sequential number
• Issue: Issue of document
• Date: Date of issue
• Project: Name of project using the component
• Prepared by Name of the person submitting the PAD
• Approval requested by: Name of the company submitting the PAD
• Family: Capacitor, resistor, etc. (Refer ECSS Family Code)
• Group: Ceramic, tantalum, etc. (Refer ECSS Group Code)
• Component Number: In accordance with the procurement specification
• May be generic to cover different range of parts (with justification): e.g. range of resistors or capacitors or variants for connectors & accessories
• Commercial Equivalent Designation Self Explanatory
• Technology/Characteristics: Additional details of the components covered by the PAD
• Pure tin free (Y/N) When tin ≥ 97% (inside the component and terminations)
• Generic specification: Relevant specification
• Detail specification: Relevant specification with issue and revisions
• only required for non qualified parts
• Specification Amendment Relevant specification with issue and revisions
### PAD contents

- Quality level: As defined in it
- Procurement by: Identify the name of the company procuring the part, e.g.,
- This can be self, CPPA, distributor, manufacturer or a
  combination thereof.
- Manufacturer/County: Self-explanatory.
- Approval status: Information about known approvals (EPPL, ESCC,
  MIL, MIL-QML, or other approvals/standards
- etc. as applicable.
- Evaluation programme required: Y/N as applicable
- Procurement inspections and test: Y/N as applicable
- DPA sample size: Number
- Complementary tests Testing/Inspection in addition to that defined in the
  procurement specification shall be identified (e.g., PIND,
  upscreening, etc.)
- Lot Acceptance: Identify level and subgroups
- Radiation Hardness Data: Self-explanatory.
- SEL/SEU/SEFI/SET/GSE:
- Evaluation Test Data (report)
- Reference
- Reference to the test report Single Event Latchup
- Single Event Upset Single Event Transient Single Event
- Functional hardening Single Event Burnout Single Event
- Gate Rupture
- RVT Radiation Verification Test: Y/N as applicable
- REMARKS: Any additional information
- Approval customer: Signature signifies acceptance
- Approval first-level supplier: Signature signifies acceptance

### Procurement Process

#### Requirements

**Count and Damage Inspection**

**Data Receipt**

Component Store, Date code noted.

**Samples for DPA**

Upscreening if needed.

**Data review (if no buy off)**

Internal Certificate of conformance and release to kitting
Pre-cap

- Verify the wafer - get the supplier to provide a SEM inspection of die and report this (Saves money on DPA)
- Reduces your risk less chance of die failure.
- Package inspect to international standard e.g. Mil Std 883 Method 2014 or 2017, ESCC 20400 Internal visual inspection.
- Build confidence in the supplier and then delegate
- Note JAN TX is not pre-capped - we recommend that should
- There are companies that offer this service for you, CPPA or Source Surveillance organisations.

Buy off (Final Source Inspection)

- Final inspection: Witness testing
- Review the process records
- Ensure that screening and PDA are compliant
- Watch the packing and ensure meets requirements.
- If you follow this and if no LAT or Qual testing is ordered then no need for the review of data at incoming. COST SAVING !!!
Destructive Physical Analysis
How and when to do it!

- DPA- set of tests to verify the workmanship standards
- Each family should have its own sequence
- Mil Std 1580 is good basis.
- Contractors have their own internal standards too.

Normally 3-5 samples taken for DPA
Looking for build quality against a standard i.e internal visual ESCC 20400 or Mil Std 883 Method 2013
Ensure that known problems are not present,
Solder attached is good- no voids, package is hermetic, no damaged seals or metallic particles loose, no problems such as purple plague, Au-Sn intermetallics, die cratering on wire bonds etc.
Ensure that the correct materials are in the construction.

DPA How to reduce it!

- If from a continuous production line and have full traceability – component engineer can assess if a DPA of one date code can cover a spread. (Keep samples for reference though of un-DPA’ed parts)
- If a resident has verified the build all the way through and records how this why DPA? You know the build standard already. (Keep samples for reference though of un-DPA’ed parts)
- Have a detailed Constructional Analysis that’s representative.
- CPPA procurement one DPA for all users
- Qualified parts may not need DPA- part of the customer requirement that may be negotiated.
Data review

- Data for EEE components comes in many shapes and sizes;
  - Purchase order can request:
    - CoC, EIDP, LAT, RVT, QCI.
- Reports are provided on request and payment!
- At incoming the data should be reviewed:
  - Check CoC ensure that is what was ordered.
  - Review lot screening records- and check the PDA/ lot failure criteria
  - Check the radiation results
  - Check LAT results.
  - Ensure components not subject to a NCR or an alert.

Post Data Review Check list:

- Prior to release on an internal CoC to stores the purchasing company should have:
  - Purchase order
  - Goods receipt note and inspection report
  - Data review report and data pack
  - Pre cap and Buy off reports
  - DPA pass/fail report
  - Components in suitable packing
- All data and DPA samples should be archived.
Component Evaluation and Qualification

An evaluation defined in ESCC Basic Specification No. 22600. The purpose of the evaluation of a component is to decide in the most cost-effective manner, if there is sufficient justification to proceed to qualification and shall include:
- The establishment of an evaluation test programme for the component.
- Definition of any corrective actions that may be required and their implementation.
- A documentation review and the finalisation of information to be contained in a Process Identification Document (PID) for the component.

Qualification defined in ESCC 20100

- All documents are completed and issued.
- A test plan is agreed
- Qualification lot manufactured to the documentation
- Tested in accordance to the plan
- Up issue of specifications where necessary
- Qualification test report valid for two years
- Entry in to ESCC QPL!

Project Qualification

- Project Qualification: testing that meets the project specific needs:
- Manufacturer assessment – check stable technology.
- LAT or Extended life test only
  - C.A and some testing?
- Risks with this approach!
  - No supplier control
  - Short term relationship only
  - Don’t understand the component that you have procured.
  - Customer may not accept this!
Preferred is Qualified right?

- WRONG!
- Preferred means exactly that:
- Qualified could be preferred but not
- Qualified means that it has been through a structured evaluation and qualification test.
- ESCC has a EPPL
- QPL

EPPL

- Split in to 2 parts:
  - Part 1
    - those preferred and qualified or are about to be qualified.
    - Data / supplier knowledge exists that allows the users to procure at a lower risk, often project will state no LAT is necessary or perhaps waive DPA (in some cases)
  - Part 2
    - Non European suppliers sit here
    - European suppliers where there is limited knowledge on the technology or have had some limited procurement history.
    - Procurement should be tightly managed
Alerts and Non Conformances

- ESA has an Alerts system:
  - [http://alerts.esa.int/](http://alerts.esa.int/)
  - ESCC has a Non Conformance system- that’s the advantage of ESCC components we manage the aspects with you!
  - Alerts when they come out should checked against the parts list- NRB may be required.
  - Any one can contact ESA with a preliminary alert- will be investigated and answers sought.
  - If alert required will be issued.
Objectives of the ESA Alert System

- Facilitate exchange of information on problems experienced in ESA projects
- Eliminate or minimise their impact
- Prevent their recurrence on other projects
- Enhance competitiveness of European space industry by avoiding waste and mistakes
What Is An Alert:

- a report
- used to provide a prompt warning on
  - failures
  - problems
which may affect more than one user, or may re-occur in other projects, if no preventive actions are taken.

An Alert describes:

- the observed problem
- its cause
- actions to be taken:
  - to correct it
  - to prevent its recurrence
- comments from the manufacturer
ESA Alerts cover failures related to:

- EEE parts
- mechanical parts
- pyrotechnic devices
- materials
- test equipment
- software used by several users
- equipment procured against a supplier’s specification
- civil aviation & military equipment

ESA Alerts also address problems with:

- safety
- manufacturing processes
- handling procedures
- standard test methods
- standard operational procedures
- software development & test methods and tools
- continuity of production of an item
**Criteria to issue an Alert**

ESA Alerts are only issued when:

- the observed problem may apply to more than one project or organisation and
- the problem was observed while the item was applied within its specified limits and
- a preliminary investigation has provided evidence of the root cause of the problem and
- the problem is confirmed not to be of a random nature

---

**How Alerts are processed**

- Preliminary Alert Information (PAI) form filled-in by the Alert originator
- PAI revised by ESA technical committee
- Revised PAI sent to manufacturer for comments
- Manufacturer’s reply evaluated by ESA technical committee
- Recommendation whether or not to issue Alert
- Final ESA Alert issued and distributed within and outside ESA
**Processing of Alerts Flowchart**

1. Fill PAI
2. Designate technical experts
3. Evaluate PAI
4. Could be an Alert?
   - YES: Raise Alert? (NO: Close case)
   - NO: Send PAI to manufacturer
5. Evaluate manufacturer reply
   - YES: Publish Alert
   - NO: Evaluate manufacturer reply

**ESA Alerts Distribution**

Presently ESA Alerts are distributed to:

- ESA Projects
- ESA technical departments
- ESA contractors
**ESA Alert Focal Point**

- Coordinate Alert preliminary investigation
- Organise & support proceedings of ESA Alert Committee
- Publish Alerts on the web
- Follow-up of actions to be implemented by manufacturer
- Register new Users to the System

---

**Alert Coordinators**

*Interface between company and ESA:*

Large companies with different geographical locations have more than one Alert Coordinator.
The role of the Technical Experts

Review Preliminary Alert
Information

Assess failure / problem
against criteria for issuing
alert

Define recommended actions
→ to solve failure/ problem
→ to prevent recurrence

Recommend whether
to issue Alert or not

Assess:
→ Manufacturer’s response
→ Alert corrective actions
→ Feedback from users
**ESA Alert System Web Site**

www.estec.esa.nl/qg/alerts!

It allows users to:
- Browse ESA Alerts
- Search ESA Alerts
- Request Access
- Submit PAI on-line
- Submit feedback/comments on-line

Access to the system restricted to registered participants only

---

**The Deviation and Waiver**

- When a RFD/RFW is to be raised; it will be a deviation from a requirement or a request to reduce a requirement.
- This is submitted in a configured document to the customer chain. Process is similar to a PAD.
- Unique number, cites requirements that cant or consider not necessary to meet.
RFD-RFW do’s and don'ts

<table>
<thead>
<tr>
<th>Do</th>
<th>Don’t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keep the report brief but add engineering justification/ analysis</td>
<td>Cite cost and schedule as only reasons</td>
</tr>
<tr>
<td>Ensure that the item is reported as early as possible</td>
<td>Wait to the last minute</td>
</tr>
<tr>
<td>Ensure that the item is addressed for the current program requirements</td>
<td>Place a blanket RFW/RFD, one programs requirements may differ from others.</td>
</tr>
<tr>
<td>Plan the activity and list the consequences to the project of meeting the requirement</td>
<td>Assume that the RFD/RFW will be agreed. This is dependent on the mission risk.</td>
</tr>
</tbody>
</table>

Failure Analysis and why do it!

- **Role of failure analysis:**
  - Expensive and time consuming but!
  - If don’t do it could end up with systematic failure
  - Batch problems can be identified
  - Handling or mis-applications can be found
Where can you go to get a failure analysis done?

First there are some dos and don'ts:
You need to be aware of what you have procured: if the parts contain toxic substances then you must warn whoever, i.e. BeO.
If the components are export license restricted then failure analysis of shipping to third parties have legal issues.
Destructive analysis of components needs to be recorded – there are tax issues involved.

Who can do a failure analysis?

- Central Parts Procurement Agents often have access to failure analysis facilities.
  - It is a mix of applications engineering knowledge
  - Science
  - Electrical test / characterisation
  - Physical analysis
- Universities and ESA has failure analysis capabilities too.
- Complex devices such as FPGA, ACTEL for instance could be ITAR controlled, but even when not they are slow but supportive at doing a failure analysis.
Component Storage – the date code and the re-life

- Date codes have various definitions beware of what these are!
- Maximum shelf life contract defined or referenced to standard.
- Customers require in their contracts that components shall be relifed or not mounted if within a period (typically 6 months) of their shelf life
- Relife can be permitted.

Storage

- **Best practices for storage are:**
  - Controlled environment (Nitrogen POD) and limited access.
  - Minimise handling, temperature cycling and interference.
  - NB ensure no acetic acid bearing foams, pink plastic ESD bagging is not wise as this is not considered ESD safe in a controlled environ.
- **Relife:**
  - Testing to verify good, sampling or 100% (customer approved)
  - Visual and electrical
  - Extension of date code use.
Common Component issues that are cyclic

- Purple Plague: Al/Au intermetallics, diffusion mechanism that weakens bonds and changes resistance of interconnections.
- Residual gas failures: 5000ppm limits exceeded.
- Crimp problems due to incorrect tool calibration.
- Incorrect burn in conditions or test set up at supplier.
- Soldering problems due to contamination.
- Gold Tin brittle intermetallics- degold!
- ESD failures due to loss of environmental control.

Component issues a Flavour of what a component engineer needs to Know

- Capacitors- ceramic- failures at low voltage CKR06 / CKR05 risk mitigation 85/85 testing- due to Ag migration.
  - 85/85 testing value for caps- delamination and migration.
  - CKR06 >0.47uF 50V risk of I.R. failures NASA recommend don’t use (see NPSL).
- Caps: COTS – pure tin finish.
- Caps: Solder finish requires Ni barrier due to solder leaching.
Component issues a Flavour of what a component engineer needs to Know

• Tantalum capacitors;
  – ESA alerts on these devices: application must be very well understood.
  – Devices must be surge current tested.
  – Mil Prf 39003 and Mil Prf 55365 three options for surge-room temperature surge testing not good enough!
  – ESCC 3002, 3011 and 3012 Surge is in the specification.
  – Don not reverse bias!
• Design and correct usage vital
• Wet Tants: 125V not advised for use (NASA!)

Wires and cables

• Commercial, Mil and ESCC wires vary.
• Only ESCC wires prevent red plague (copper conductor oxidation).
• ESCC wires have 2um of Ag so passes the Anthony Brown test
• ESCC wires require good cut through and abrasion resistances.
• ESCC cables where there has been a break and weld it is marked on the cable and we don’t use that part!
Connectors

- Connector shells cannot be Cd or Zn plated- outgas in thermal vac and damaged chamber if lucky!, Toxic ! Outgas and damage optics in orbit !
- Connector plugs and sockets good for limited number of mates- use a log to ensure that's not exceeded.
- Connector savers used to protect flight interfaces.
- Crimp tools all calibrated and regular checks made.
- Solder joints inspected.
- Pins and buckets inspected for debris and good quality plating to avoid welds and glitches.

Resistors

- Thin Film and Foils: just because they are high value they are not ESD robust !
- Ensure that they are correctly terminated – pure Sn.
- Solder mounting and issue as is handling.
- Common myth- the difference between TiW and NiCr resistors- myth is that Cr diffuses and change in value compared to TiW seeded resistors. Actual case is sputtering system.
Discrete Semiconductors

- Classic is Bipolar devices are rad hard!
- Misconception JANTX and JAN TXV are space quality, ONLY JAN S is!
- You need to PIND test these and DPA is highly recommended.
- Watch out on date codes! Small orders may get a composite order.

Programmable devices 1/2

- FPGA: justify the use, also if going to use the device beware of the QA and export issues.
- EEPROM has various quality assurance aspects- be aware of alerts!
- Data retention is an issue in EEPROMS
- Write in orbit may have risks in EEPROMS
- Software configuration is always an issue!
Programmable devices: 2/2

- ESA projects require that programmable devices are burned in:
- PROMS- burn in post programming
- FPGA: Post programming burn in is an ESA recommendation
  - Justification for use is also an issue.
  - ASIC approach is preferred!

---

MMIC’s

Verify that the process and design of MMIC are adequate in accordance with ECSS Q60-12
WAT testing is important- verifies the wafer quality
ensure that this complies to ECSS Q60-12.
Ensure that the metallisation Scheme is not H2 sensitive
Verify with LAT testing.
Common issues

• When order dice do not have these delivered in Gel packs or minimise time on Gel- contaminates the surface. May see good X-ray then die falls off!
• Pay attention to wire bonding SPC data. (plasma cleaning is good practice prior to bonding)
• Do not assume that if it comes from the same manufacturer then it is a qualified product.
• When some one states “qualified” always ask to what?
  – Mil 883B is not a qualification status, equivalent qualifications- what does that mean? Etc?

Some Common Issues

• COTS:  
  – Risks
• Counterfeits  
  – Risks
Conclusion:

- Very few EEE parts failed due to poor manufacture
- Misapplication – wrong part, wrong function or in appropriate quality most common.
- Ensure that you document and assess technologies uses
  - Protects your business
Radiation Hardness Assurance

Ali Mohammadzadeh (TEC-QCA)
Radiation Effects and Components Test Section
Petteri Nieminen (TEC-EES)
Space Environment and Effects Section

Majority of slides presented are from RADECS 2003 short course.

RADECS 2003 short course by:
• Sophie Duzellier
• Gordon Hopkinson
• Renaud Mangeret
• Ali Mohammadzadeh
• Christian Poivey
• Juan Cueto Rodriguez

Radiation Environment Presentation by:
• Petteri Nieminen
RHA definition

- RHA consists of all activities undertaken to ensure that the electronics and materials of a space system perform to their design specifications after exposure to the space radiation environment

- Deals with environment definition, part selection, part testing, spacecraft layout, radiation tolerant design, and mission/system/subsystems requirements

- Radiation Hardness Assurance goes beyond the piece part level
RHA Overview

MISSION/SYSTEM REQUIREMENTS

SYSTEM AND CIRCUIT DESIGN

PARTS AND MATERIALS RADIATION SENSITIVITY

RADIATION ENVIRONMENT DEFINITION

RADIATION LEVELS WITHIN THE SPACECRAFT

ANALYSIS OF THE CIRCUITS, COMPONENTS, SUBSYSTEMS AND SYSTEM RESPONSE TO THE RADIATION ENVIRONMENT

Typical Science Project Organization

Science Team

Mission System Engineer

Project Management

Finance & Administration

Reliability & Quality Assurance

Science Instruments

Science Instrument #1

Science Instrument #2

Science Instrument #3

Ground Systems

Spacecraft

Launch Vehicle

S/C System Engineer

Reliability & Quality Assurance

Parts Radiation Contamination I&T

Forecast & Navigation Control

Command & Data Handling

Finance & Administration

Mechanical

Thermal

Communications

Power
Sensible RHA Programmatic A Two-Pronged Approach

• Lead radiation PROJECT engineer
  – Integrate radiation like other engineering disciplines
    • Parts, thermal,...
  – Single point of contact for all radiation issues
    • Environment, parts evaluation, testing,...
• Follow a systematic approach to RHA
  – RHA active early in program reduces cost in the long run
    • Issues discovered late in programs can be expensive and stressful
• Mission requirements and RHA methodologies vary to ensure mission performance
  – What works for a shuttle mission may not apply to a deep-space mission

Late Changes => Bigger Impact

<table>
<thead>
<tr>
<th>Time</th>
<th>Definition</th>
<th>Design Stage</th>
<th>Production Stage</th>
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</thead>
<tbody>
<tr>
<td>concept design</td>
<td>specifications</td>
<td>drawings</td>
<td>interface specs</td>
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<tr>
<td>plans/strategies</td>
<td>test specs</td>
<td>schedule</td>
<td>procurement specs</td>
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<td>estimates</td>
<td>packaging</td>
<td>purchase orders</td>
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<td>reviewing</td>
<td>design proving tests</td>
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<td>configuration management</td>
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</table>
Radiation Hardness Assurance During the Program Life

- Pre Phase A, Phase A – (Preliminary Requirement Review, PRR)
  - Draft environment definition
  - Draft hardness assurance requirements (top level)
  - Preliminary studies (e.g. GAIA mission irradiation characterisation of CCDs)
- Phase B – (Preliminary Design Review, PDR)
  - Final environment definition
  - Electronic design approach
  - Preliminary spacecraft layout for shielding analysis
  - Preliminary shielding analysis & hardness assurance requirements update
  - Preliminary Radiation Analysis Report
- Phase C – (Critical Design Review)
  - Radiation test results
  - Final shielding analysis & final hardness assurance requirement
  - Final Radiation Analysis Report (including WCA and FEMICA)
- Phase D
  - Radiation Lot Acceptance Tests (RLAT)
- Phase E (Utilisation)
  - Failure analysis (Lessons learned)
**System Hierarchy**

- **System**
  - **Sub System**
    - **Unit**
      - **Building Blocks**
        - **Components**

**Project Requirements Flow-Down**

- **Level 1**
  - **Level-1 Requirements Document**

- **Level 2**
  - **Project Plan**
  - **Mission Requirements Document**
  - **Mission Assurance Requirements**

- **Level 3**
  - **Subsystem Specifications**
    - **Level 4**
      - **Var Emittance Coatings**
      - **Solar Array**
      - **Li-Ion Battery**
      - **Magnetometer**
      - **Sun Sensor**
      - **Nutation Damper**
      - **X-ponder**
      - **Antenna**
      - **Thrust Cntl Elec.**
      - **Propellant Tank**
      - **Diag. S/W**
      - **Power/FSW**
      - **Autonomous GROUNDS S/W**
      - **Release Mech Actuators**
Radiation Requirements Flow-Down

Environment requirement
- Particle fluxes, incident and shielded
- Dose versus depth curve
- Damage versus depth curve
- LET spectra

Requirements
- Radiation top level requirements and design margins
- Tolerable system failure rate
- Requirement for telemetry degradation in orbit

Orbit & mission duration
Spacecraft layout
Spacecraft mass
Cost
Risk

Mass distribution
Location of sensitive parts
Radiation tolerance of parts

System Level
Sub-System Level
Electronic box Level
Component Level

Electronic box Level
- Mass budget
- Box SEE tolerance level
- Top level requirements & design margins
- Rules for WCA of degradation
- Requirement for telemetry degradation in orbit

Component Level
- Test requirements
- Part SEE tolerance level
- Derating specifications
- Top level requirements

Board mass distribution
Location of sensitive parts
Radiation tolerance of parts

Part selection
Test method
Lot variation

Space Radiation Environments and Shielding

Petteri Nieminen
Space Environments and Effects Section
Solar Events
Solar Energetic Particle Event Characteristics

- Radiation fluxes high for ~days
- Fluences high enough to cause damage => importance of proper shielding
- Include protons and heavy ions
- Energy spectrum highly variable
- Essentially unpredictable, however efforts dedicated to address the problem in various Space Weather initiatives
- Analysis methods are *statistical* (e.g. JPL-91 model, available in SPENVIS)
- Also geomagnetically shielded
Space Radiation: Solar Events of October-November 2003

Images by the SOHO and GOES spacecraft

STS-116 mission to ISS

Flux (1/cm²/sr/s)

>10 MeV

>50 MeV

>100 MeV

STS-116 spacewalk 1

STS-116 spacewalk 2
Apollo missions: Solar maximum

~ 40 Sv acute skin dose (without shielding) from August –72 SPE. Potentially very serious for the lander/EVA

0.5 Sv annual limit for ISS astronauts

20 mSv annual limit for radiation workers on Earth

20 mSv annual dose from natural sources on Earth
Particle Event Propagation

TIME = 1.82544 h

LOG$_{10}$(Number Density, cm$^{-3}$)

SUN

ISO LWS Shielding simulation

1 MeV protons
30 MeV protons
100 MeV protons
1 GeV protons
Earth’s Radiation Belts

Radiation belts: Static picture
(AE-8, AP-8)

“Electron Belt”

“Proton Belt”
Features of Radiation Belts

- Inner belt is dominated by a static population of energetic protons up to ~300 MeV energy range
  - Product of Cosmic-Ray Albedo Neutron Decay
  - Inner edge is encountered as the South Atlantic Anomaly (SAA)
  - Dominates the Space Station and LEO spacecraft environments

- Outer Belt is dominated by a dynamic population of energetic electrons up to ~5 MeV;
  - Frequent injections and dropouts associated with storms and solar material interacting with magnetosphere
  - Dominates the geostationary orbit environment and Navigation (Galileo, GPS) orbits, as well as certain Science missions in highly elliptic orbits (XMM-Newton, INTEGRAL)
Variable environment

Space Environments and Effects Section

Colour-coded Dose Rate from REM on STRV in GTO

Geo-stationary Altitude

L (~Radial Distance) (Re)


High

Dose

Low

Outer Belt

“Slot”

Inner Belt
Electron propagation

- Tracks much more convoluted than with protons
- Bremsstrahlung production
- 1D Shielding analyses with tools such as MULASSIS or SHIELDOSE
- Most complete method is Monte-Carlo e.g. Geant4
ESA Standard Radiation Environment Monitor (SREM)

SREM
Geant4 model

INTEGRAL    ROSETTA    ROBA-1    HERSCHEL    GSTB V2    PLANCK    GAIA

SREM on PROBA: protons and electrons

South Atlantic Anomaly (SAA)
Cosmic Rays
Cosmic Rays

- Flux ~ 4 particles/cm²/sec in space, anticorrelation with solar activity
- Atmosphere shields Earth's surface from "primary" cosmic rays
- Collisions in upper atmosphere produce "secondary" cosmic rays - some reach ground level (seen in "neutron monitors")
- Average person is crossed by ~ 100 relativistic muons per second
- Discovered in 1912 by Austrian Victor Hess
- Supernovae produce high energy cosmic rays, accelerated by moving shocks, as suggested by Enrico Fermi in 1949.
- Charged particles accelerated to near speed of light (can reach ~10¹⁹ eV range. The most powerful particle accelerators on Earth "weak" in comparison)
- Definitive model the CREME series by NRL, available in SPENVIS

Cosmic Rays: anticorrelation with solar min/max periods
Fluxes and Composition

Cosmic ray proton spectra at solar maximum and minimum

Hydrogen
Solar Min
Solar Max

Composition of Cosmic Rays

Adams (NRL reports in “CREME series”)

Composition

Energy = 2 GeV/\text{n}, Normalized to Silicon = 10^6

H
He
C
O
Si
Fe
Zr
Ba
Pt
Pb

Individual Elements
Even-Z Elements
Elemental Groups
Geomagnetic Shielding

IGRF 82

Within the Magnetosphere - Geomagnetic Shielding

Energy of Iron ion (MeV/amu)
LET ("Integral Heinrich") Spectra

- Combines all ions into one curve;
- Total number of particles with a given LET (so combines slow low-Z ions with fast high-Z ions);
- Useful if effects are caused only by the ionisation track (e.g. SEU, SEL).

Planetary Radiation Environments
Issues for Mars:
- SPE and GCR fluxes at 1.5 AU
- Broad range of altitudes
- Seasonal, diurnal and local variations of atmospheric pressure
- For UV and X rays: dust storms
- Surface backscattering and neutrons $\Rightarrow$ local geology
- Local magnetic fields in the southern hemisphere

MGS at mapping orbit altitude $\sim$400 km
1" by 1" resolution
Mars relic magnetic fields implemented in Geant4

PLANETOCOSMICS software, L. Desorgher, University of Bern

Martian Aurorae observed by Mars Express

1 MeV electrons
10 MeV electrons
100 keV protons
10 MeV protons

Magnetic shielding on Mars at -47.8° N, 174° E
Jupiter: Extreme radiation environment

For an unshielded astronaut on Europa, lethal radiation dose in minutes

John Sørensen, ESA (TEC-EES)
More information

- ECSS-E-10-04 Space Environment Standard: http://space-env.esa.int/ECSS/ecss_10_04.html
- GEANT4 for Space: http://geant4.esa.int/
- ESA Space Environments and Effects Section: http://space-env.esa.int/R_and_D/overview_rev.htm
- ESA Space Weather site: http://esaspaceweather.net/index.html
Objectives:
• Prevent catastrophic and functional failure due to radiation
• Assure the total End of Life functionality.

Main problems:
• Many unknown devices
• High lot-to-lot variability
• High test campaign costs
• Availability of radiation test facilities
• Variety of radiation test standards
• Limited number of Radhard devices
Interaction of Radiation with Electronic Devices and Materials.

The effects of radiation on electronic devices and materials depend on:

- **Type of radiation** (photon, electron, proton...)
- **Rate of interaction**
- **Type of material** (Silicon, GaAs..)

Consequences: Ionization and Displacement Damage

Basic concepts. Ionization.

**Ionization**: Process of removing electrons from atoms.

The creation of electron-hole pairs in the material causes:

- *Transient effects in the device bulk active area*
- *Long term effects in oxides*

Consequence: Alteration of the electrical characteristics for electronic devices.
Basic concepts. Units

Absorbed dose.
Energy absorbed locally per unit mass due to ionisation
The Gray is the SI unit for absorbed dose, however, traditionally the rad (Radiation Absorbed Dose) was (and still is) used.

\[ \text{Gray (Gy)} = \frac{J}{kg} \text{ (S.I.)}, \]
\[ 1 \text{ Gy} = 100 \text{ Rad} \]

Dose equivalent.
Damage equivalent. Employed in medical applications.

Sievert, Rem (Roentgen Equivalent Man)

\[ \text{Sv} = Q \times \text{Gy} \quad Q : (1 \text{ gamma, 10 neutron}) \]
\[ 1 \text{ Sv} = 100 \text{ rem} \]

The dose must always be referred to the absorbing material.
Relevant materials are GaAs, Si-SiO2.

Long-term effects

Electron and proton exposure result in long-term effects. Main effects:

- Oxide charge trapping. *Holes trapped in SiO}_2
- Creation of interface states at SiO}_2-Si interface. *Chemical bonding changes at interface.*

Induces changes in \( V_{th} \) and leakage \( \rightarrow \) The electrical performance is degraded.
Effects in MOS devices

Main consequences

*Increased leakage, stand-by and operating currents*
- Degradation of input logic levels
- Reduction in noise margin
- Reduction in output drive or fanout.
- Increased propagation delay
- Eventual functional failure
- Worst case when biased

Effects in Bipolar devices

The passivation oxide layer (protection) is thicker than in CMOS

*Process similar to MOS devices: Charge trapping + Interface States*

\[ I_E = I_C + I_B \]

Main effects
- Gain degradation (\( \beta \) or \( h_{FE} \))
- Leakage

Lower-quality oxide \( \rightarrow \) Greater Damage
Effects in Bipolar devices. ELDRS.

*The Enhanced Low Dose Rate Sensitivity (ELDRS)*

- Some bipolar based devices illustrate higher degradation when irradiated at lower dose rates.
- Most spacecraft are operated in Low Dose Rate Environment.

![Time & cost for testing](image)

<table>
<thead>
<tr>
<th>Krad(Si)</th>
<th>2 Krad/h</th>
<th>360 rad/h</th>
<th>36 rad/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5 hours</td>
<td>1.1 days</td>
<td>11.5 days</td>
</tr>
<tr>
<td>50</td>
<td>25 hours</td>
<td>5.7 days</td>
<td>57.8 days</td>
</tr>
<tr>
<td>100</td>
<td>50 hours</td>
<td>11.5 days</td>
<td>115.7 days</td>
</tr>
<tr>
<td>300</td>
<td>150 hours</td>
<td>34.7 days</td>
<td>347.2 days</td>
</tr>
</tbody>
</table>

An accelerated test is needed!!

---

Effects in Bipolar devices. ELDRS.

Low quality of the oxide $\Rightarrow$ Increase in the net positive charge in the oxide covering the emitter-base junction.

![Graph](image)

Effects in Bipolar devices

Lot to lot variability

- More variability at lower dose rates
- Manufacturing process determinant (impurities)

Technologies susceptible to total ionising dose effects

<table>
<thead>
<tr>
<th>Technology category</th>
<th>Sub categories</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOS</td>
<td>NMOS, PMOS, CMOS, CMOS/SOS/SOI</td>
<td>Threshold voltage shift, Decrease in drive current, Decrease in switching speed, Increased leakage current</td>
</tr>
<tr>
<td>JFET</td>
<td></td>
<td>MFE degradation, particularly for low-current conditions</td>
</tr>
<tr>
<td>Analogue microelectronics (general)</td>
<td></td>
<td>Changes in offset voltage and offset current, Changes in bias-current, Gain degradation</td>
</tr>
<tr>
<td>Digital microelectronics (general)</td>
<td></td>
<td>Enhanced transistor leakage, Logic failure from (1) reduced gain (BJT), or (2) threshold voltage shift and reduced switching speeds (CMOS)</td>
</tr>
<tr>
<td>CCDs</td>
<td></td>
<td>Increased dark current, Effects on MOS transistor elements (described above), Some effects on CTE</td>
</tr>
<tr>
<td>APS</td>
<td></td>
<td>Changes to MOS-based circuitry of imager (as described above) -- including changes in pixel amplifier gain</td>
</tr>
<tr>
<td>MEMS</td>
<td></td>
<td>Shift in response due to charge build-up in dielectric layers near to moving parts</td>
</tr>
<tr>
<td>Quartz resonant crystals</td>
<td></td>
<td>Frequency shifts</td>
</tr>
<tr>
<td>Optical materials</td>
<td>Cover glasses, Fibre optics, Optical instruments</td>
<td>Increased absorption, Variation in absorption spectrum (coloration)</td>
</tr>
<tr>
<td>Polymeric surfaces (generally only important for materials exterior to spacecraft)</td>
<td></td>
<td>Mechanical degradation, Changes to dielectric properties</td>
</tr>
</tbody>
</table>
Conclusions

Sensitivity to total dose is strongly technology and manufacturing processes dependant. Hence, a simplified model for accurate prediction of total dose effects is not available.

A correct component selection requires good knowledge of the radiation environment (specifications) and accurate mission parameters.

Actual models for predicting total dose effects needs to be updated resulting in cost savings (related to components) for most space programs.

Displacement Damage
Displacement Damage

- Particles (e.g. protons, neutrons, electrons) displace atoms from the crystal and create vacancy-interstitial (Frenkel) pairs:

Displacement Damage

\[ PKA = \text{Primary Knock-on Atom} \]
Displacement Damage

Vacancies and interstitials migrate, either recombine or form stable defects.

With ion irradiation, get migration for $T > 150$ K interstitials; $170$ K vacancies.

Non Ionizing Energy Loss (NIEL)

- **Number of displacements (I-V pairs) is proportional to PKA energy** (Kinchin-Pease: $N = T/2T_D$)
  - In cascade regime the nature of the damage does not change - just get more cascades
    - nature of damage independent of PKA energy
  
- **Extend this to point defects also**
  - nature of damage independent of PKA energy
  - so independent of incident particle energy and type
  - amount of damage proportional to the energy that goes into displacements - Non ionizing energy loss (NIEL)
    - about 0.1% of total energy loss
Non Ionizing Energy Loss (NIEL)

- Most (~90%) of Is and Vs recombine, but the rest migrate and form stable defects:
  - P-V (E centre), O-V (E centre) V₂ (divacancy), V₃, V₄, V₂O, C₆, C₇.
- Assume number of defects is proportional to NIEL & same constant - whether isolated or in clusters
  - true for divacancy but maybe not for all defects
  - assume defect inventory is independent of PKA energy

Assume underlying electrical effect proportional to defect concentration (Shockley Read Hall theory)

\[
\text{damage} = k_{\text{damage}} \times \text{displacement damage dose} = \int NIEL(E) \frac{d\phi(E)}{dE} dE
\]

Terms & Units

- **NIEL** (displacement kerma = Kinetic Energy Released to Matter)
  - keVcm²/g or MeVcm²/g
- **displacement damage cross section** (per atom)
  - MeVmb in Si, 100 MeVmb = 2.144 keVcm²/g
  - Si: 10 MeV protons: 7.885 keVcm²/g, 1 MeV neutrons 2.037 keVcm²/g
  - 368 MeVmb 95 MeVmb
  - GaAs: 70 MeVmb
- **displacement damage dose**
  - keV/g or MeV/g
  - in terms of equivalent fluence of monoenergetic particles
    - e.g. 10 MeV protons/cm² or 1 MeV neutrons/cm² DDEF
  - Gy (old unit, rad, still used !)
Device Effects

<table>
<thead>
<tr>
<th>Technology category</th>
<th>sub-category</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>General bipolar</td>
<td>BIT</td>
<td>NIEL degradation in BITs, particularly for low-current conditions (PNP devices more sensitive to DD than NPN)</td>
</tr>
<tr>
<td></td>
<td>diodes</td>
<td>Increased leakage current, increased forward voltage drop</td>
</tr>
<tr>
<td>Electro-optic sensors</td>
<td>CCDs</td>
<td>CTE degradation, increased dark current, increased hot spot, increased bright columns, random telegraph signals</td>
</tr>
<tr>
<td></td>
<td>APS</td>
<td>Increased dark current, increased hot spot, random telegraph signals, reduced responsivity</td>
</tr>
<tr>
<td>Photo diodes</td>
<td></td>
<td>Reduced photovoltage, increased dark currents</td>
</tr>
<tr>
<td>Photo transistors</td>
<td></td>
<td>NIEL degradation?, increased dark current?</td>
</tr>
<tr>
<td>Light-emitting diodes</td>
<td>LEDs (general)</td>
<td>Reduced light power output</td>
</tr>
<tr>
<td></td>
<td>Laser diodes</td>
<td>Reduced light power output, increased threshold current</td>
</tr>
<tr>
<td>Opto-couplers</td>
<td></td>
<td>Reduced current transfer ratio</td>
</tr>
<tr>
<td>Solar cells</td>
<td>Silicon</td>
<td>Reduced short-circuit current, reduced open-circuit voltage, reduced maximum power</td>
</tr>
<tr>
<td></td>
<td>GaAs, InP etc</td>
<td></td>
</tr>
<tr>
<td>Optical materials</td>
<td>Alkali halides</td>
<td>Reduced transmission</td>
</tr>
<tr>
<td>Radiation detectors</td>
<td>Semiconductor γ-ray &amp; X-ray detectors</td>
<td>Reduced charge collection efficiency (calibration drifts, reduced resolution) Power rating characteristics HPGe show complex variation with temperature</td>
</tr>
<tr>
<td></td>
<td>Si, HPGe, CdTe, CZT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Semiconductors charged-particle detectors</td>
<td>Reduced charge collection efficiency (calibration drifts, reduced resolution)</td>
</tr>
</tbody>
</table>
Device Effects - Examples

Voltage Regulator

Rax et al.
IEEE Trans.
Nucl. Sci. vol 46(6),
pp. 1660-1665, 1999

Device Effects - Examples

Solar Cells

Device Effects - Examples

LEDs

Johnston
NSREC200
Short Course
Notes

Device Effects - Examples

Laser Diodes

Johnston et al.
vol 48(6), pp. 1764-1772, 2001
Device Effects - Examples

Optocoupler


Device Effects - Examples

CCD
Dark Image:
dark spikes &
CTI damage

NIEL Deviations: GaAs Devices


But NIEL scaling is a good first approximation
removes most of the energy (and particle) dependence
without it, testing/prediction would be much more complicated

Summary

- Mechanisms of displacement damage
- Electrical effect of lattice defects
- NIEL scaling
- Devices and parameters affected
- Modeling and prediction
- Device selection
Essential Reading

- **IEEE NSREC short course notes**
  - 1999 Cheryl Marshall
    Proton Effects and Test Issues for Satellite Designers, Part B: Displacement Effects
  - 2000 Allan Johnston
    Optoelectronic Devices with Complex Failure Modes

---

Single Event Effects
Introduction

electrical perturbation induced by the natural space environment (high-energy ionising particles: heavy ions –HI-, protons –p+-)

results in non-destructive / destructive effects
  data corruption
  transient disruption
  high current/E-Field conditions

affects many types of devices and technologies impacts on system performance

of increasing importance
  reduced feature sizes & higher integration (lower noise margin)
  higher complexity (several operating modes)
  use of non hardened devices (COTS)

Overview of the Single Events Effects

<table>
<thead>
<tr>
<th>Event</th>
<th>Effect</th>
<th>Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upset - SEU</td>
<td>corruption of the information stored in a memory element</td>
<td>Memories, latches in logic devices</td>
</tr>
<tr>
<td>Multiple Bit Upset - MBU</td>
<td>several memory elements corrupted by a single strike</td>
<td>Memories, latches in logic devices</td>
</tr>
<tr>
<td>Functional Interrupt - SEFI</td>
<td>loss of normal operation</td>
<td>Complex devices with built-in state/control sections</td>
</tr>
<tr>
<td>Transient - SET</td>
<td>impulse response of certain amplitude and duration</td>
<td>Analog and Mixed Signal circuits, Photonics</td>
</tr>
<tr>
<td>Disturb - SED</td>
<td>momentary corruption of the information stored in a bit</td>
<td>combinational logic, latches in logic devices</td>
</tr>
<tr>
<td>Hard Error - SHE</td>
<td>unalterable change of state in a memory element</td>
<td>Memories, latches in logic devices</td>
</tr>
<tr>
<td>Latchup - SEL</td>
<td>high-current conditions</td>
<td>CMOS, BiCMOS devices</td>
</tr>
<tr>
<td>Snapback - SESB</td>
<td>high-current conditions</td>
<td>N-channel Mosfet, SOI dev.</td>
</tr>
<tr>
<td>Burnout - SEB</td>
<td>destructive burnout</td>
<td>BJT, N-channel Power MOSFET</td>
</tr>
<tr>
<td>Gate Rupture - SEGR</td>
<td>rupture of gate dielectric</td>
<td>Power MOSFETs</td>
</tr>
<tr>
<td>Dielectric Rupture - SEDR</td>
<td>rupture of dielectric</td>
<td>Non-volatile NMOS struct., FPGA, linear devices...</td>
</tr>
</tbody>
</table>
Overview of the Single Events Effects

Non destructive effects

SEU : Single Event Upset (« soft » error)

Active storage element

![Diagram of active storage element with data transitions P1 (OFF) to P2 (ON) and data transitions N1 (ON) to N2 (OFF)]

Passive storage element

(SEU also in active storage element)

![Diagram of passive storage element with bit line, word line, Vref, pass transistor, storage capacitor, and sense amplifier]

==> MBUs, block errors, SEFIs
Overview of the Single Events Effects

Non destructive effects

SET: Single Event Transient
described by a voltage amplitude
and duration

LM124 Op. Amp

<table>
<thead>
<tr>
<th>Device type</th>
<th>SET/SED pulse amplitude and duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>OP-amps</td>
<td>$\Delta V_{\text{max}} = V_{\text{CC}}$ &amp; $\Delta t_{\text{max}} = 40 \mu s$</td>
</tr>
<tr>
<td>Comparators</td>
<td>$\Delta V_{\text{max}} = V_{\text{CC}}$ &amp; $\Delta t_{\text{max}} = 10 \mu s$</td>
</tr>
<tr>
<td>Voltage Regulator</td>
<td>$\Delta V_{\text{max}} = 5 \text{V}$ &amp; $\Delta t_{\text{max}} = 10 \mu s$</td>
</tr>
<tr>
<td>Voltage Ref.</td>
<td>$\Delta V_{\text{max}} = V_{\text{CC}}$ &amp; $\Delta t_{\text{max}} = 10 \mu s$</td>
</tr>
<tr>
<td>PWMs</td>
<td>Double Pulse: two missing pulses, multiple missing pulses in a row, device shut off. Assess impact in specific application.</td>
</tr>
<tr>
<td>PLL</td>
<td>Transients and permanent changes in output voltage. In synthesizer circuits can cause phase, amplitude and frequency transients with duration determined by loop response.</td>
</tr>
<tr>
<td>Opto-couplers</td>
<td>Susceptible to SEU 5 Volts &amp; 100 nanoseconds.</td>
</tr>
</tbody>
</table>

Overview of the Single Events Effects

Destructive effects

SEL: Single Event Latchup

- accompanied by functionality loss
- destructive if no current limitation (excessive heating)
- power cycling to recover normal operation
Overview of the Single Events Effects

*Destructive effects*

SEB : Single Event Burnout

SEGR : Single Event Gate Rupture

\[ \Rightarrow \text{junction breakdown} \quad \Rightarrow \text{oxide breakdown} \]

SEDR : Single Event Dielectric Rupture (antifuse rupture)

---

**Summary**

wide variety of Single Event Effects

can be destructive (SEL, SEB, SEGR)

Note: Radiation susceptibility of a device is expressed as a cross-sectional area, usually in units of cm²/device or cm²/bit (the latter being used for single event upset analysis).
RHA Requirement

- RHA requirements
  - In parallel to developing the Radiation Environment Definition, the RHA requirements need to be defined.
- In many cases, companies maintain internal RHA standards
- These standards are subsequently tailored to specific projects
- Currently the Agency does not have a RHA standard
  - A RHA standard planned under ECSS (in cooperation with industry)
- The implementation of a RHA lead to documents such as
  - Radiation Environment Specification
  - Radiation Analysis Report (results fed to Worst Case Analysis and FEMICA)

Typical RHA Process

1. Input: Radiation Environment Requirement
2. Iterative process flow:
   - Shielding analysis
     - 3D Sectorial or 3D Monte Carlo
   - Predicted Radiation Environment at Part Level
3. Process flow:
   - Component TID analysis
   - Component DD analysis
   - Component SEE analysis
   - Analysis Result also fed to Design WCA and FMICA
4. System Requirements (e.g. fault tolerance requirement)
Components Division

ESA SME Course 2007
Component Engineering

Design Margin Requirement

- A radiation design margin (RDM) is defined as the ratio of the radiation tolerance or capability of a component, subsystem, or system to the specified anticipated radiation environment for part in its mission or phase of the mission.
- Requiring the RDM to exceed a minimum value ensures that allowance is made for the uncertainties in the prediction of the radiation environment and damage effects, these arising from:
  - a. Uncertainties in the models and data used to predict the environment;
  - b. The potential for stochastic enhancements over the average environment (such as enhancements of the outer electron radiation belt);
  - c. Systematic and statistical errors in models used to assess the influence of shielding, and determine radiation parameters (e.g. TID, NIEL, particle fluence) at components’ locations;
  - d. Uncertainties in the radiation tolerance of components, established by irradiation tests, due to systematic testing errors;
  - e. Uncertainties as a result of relating test data to the actual parts procured, and variability of measured radiation tolerance within the population of parts.
Design Margin

- An integral part of the requirements analysis and design synthesis process.
- The overall margin may be established by the customer or proposed by the supplier.
- In establishing margins, three aspects shall be considered:
  - Space radiation environment;
  - Calculation of radiation effects parameters, including:
    - Shielding;
    - Calculation of effects parameters (e.g. ionizing dose, displacement dose, SEE rate, instrumental background, biological effects)
  - Radiation effect behaviour of entities (components, payloads, humans, etc.).
- Allows the balancing of allocations between subsystems and subsystem elements.
- Requirements may be reduced as the design matures.
- Proper margins minimise risk and reduce the impact of requirements changes.

System Requirements

- The RHA process also takes into account system requirements such as:
  - Science requirements (important for detectors and sensors)
  - Operational Requirement
  - Subsystem Requirements
  - Unit requirement
  - Etc.
- Thus one may not look at parts in isolation
Science Requirement

Proton induced increased bulk dark current in a CCD resulting in increased noise and depending on application reduced science return. Possible mitigation, operated at lower temperatures.

Detector requirement: Maximum radiation induced Dark Current at a given temperature.

As illustrated by the SOHO CCD images above, tracking of stars difficult in solar flare conditions. Mitigation techniques, improved software star identification algorithms. Images courtesy ESA image gallery.
Circuit level requirements

Shielding

- Shielding is defined as any material between the component location and the external environment resulting in an attenuation of the radiation environment.

- The assessment of the amount, type and energy of radiation arriving at any component location therefore requires an accurate knowledge of the external environment and also Shielding.

- Application of shielding occurs in two ways:
  - “built-in” shielding, that is the fortuitous shielding afforded by materials already included in the design,
  - “add-on” shielding, that is the shielding which is added specifically for the purposes of attenuating radiation.
Shielding

- Shielding analysis level of detail depends on available shielding information (thus project phase).
- In the initial phases of a project, conservative shielding estimates are applied (most lightly shielded part of a subsystem or unit).
- If radiation levels (including secondary radiation) found acceptable, no further analysis necessary.
- If problems identified following the conservative approach, more accurate shielding analysis possibly including detailed 3D Monte Carlo particle transport simulation tools may be required (possibly also identification of mitigation techniques, e.g. addition of local shielding)
- Secondary particles: x-ray, protons, neutrons and electrons (electrons induced by gammas from RTGs)

Geometrical Model

In the initial phases of a project shielding may simply be defined as a component inside a unit. In the later stages of the project if problems are encountered, the shielding may be defined as a unit inside a sub-system, a sub-system inside a system and finally, a system within a simplified spacecraft geometry or detailed spacecraft geometry.

Note: Removal of shielding elements lead to conservative estimates however, care shall be taken that the missing elements do not result in effect enhancement.
Shielding Analysis

• Simple or detailed sectoring analysis
  – Assumes that the influence of material type is neglected and the different materials may be approximated to the equivalent mass of a single material type (typically aluminium) by a proportional change in density.
  – The sector shielding approach does not consider the physics involved in the
    • performance of graded shields,
    • dose enhancement in a silicon die close to gold contacts and/or high-Z packaging materials,
    • or in calculating the X-ray bremsstrahlung dose in a location shielded by tantalum
  – Sectoring is not appropriate for the assessment of secondary hadron levels from materials with significantly different atomic mass number from the original target material.

Monte Carlo Particle Transport

• Detailed radiation “transport” calculations provide a more accurate treatment of the radiation interaction processes. Calculates:
  – particle numbers, species, energy, and direction of propagation

• MC calculation approach may be necessary where aspects of the equipment/component performance and the influence of shielding cannot be adequately treated within a sector shielding analysis.
• MC calculation shall be based on the actual materials employed.
• In some cases 1D or 2D simulation may be adequate, however, geometry representativeness and conservatism shall be demonstrated
• The particle fluence employed is project dependent ans shall result in statistical errors within the projects design margin
An accurate spacecraft model will increase the accuracy of dose requirements.

Top Level Requirement

Subsystem dose point

ST5 - Total Mission Dose on Electronic Parts

200-35790km, 0 degree inclination, 3 months
For Displacement Damage, an Equivalent Fluence or a Displacement Damage Dose (DDD) is Defined Based on NIEL

NIEL Proton 10 MeV equivalent fluences for Silicon
ST5: 200-35790 km, 0 degree inclination, 3 months

Heavy Ion Environment is Defined for a Conservative Value of Shielding
Integral LET Spectra at 1 AU (Z=1-92) for Interplanetary orbit
100 mils Aluminum Shielding, CREME96
The Proton SEE Environment is Defined for a Conservative Value of Shielding. Orbit Average and Maximum Fluxes are Defined.

Trapped Proton Integral Fluxes, behind 100 mils of Aluminum shielding
ST5: 200-35790 km 0 degree inclination, Solar maximum

Example Proton SEE Environment

Plot produced by Hugh Evans (TEC-EES, ESA)
Typical RHA Process

- **Input**:
  - Radiation Environment Requirement
  - Shielding Requirements
  - System Requirements (e.g., fault tolerance requirement)

- **Iterative process flow**:
  - Shielding analysis
    - 3D Sectoring or 3D Monte Carlo
  - Predicted Radiation Environment at Part Level
  - Component TID analysis
  - Component DD analysis
  - Component SEE analysis
  - Analysis Result also fed to Design WCA and FMICA

- **Output**:
  - Margin Requirement

---

Parts Selection

- **Performance**
  - High reliability levels
    - Standard process designed for radiation hardness
    - Standard product with radiation hardness characterized and warranted by the manufacturer
  - Standard process designed for radiation hardness
  - Standard product

- **Commercial level**
  - Commercial process designed for radiation hardness
  - COTS

---

Reliability? Availability? Cost?
Example: Voltage Comparator

<table>
<thead>
<tr>
<th></th>
<th>TID tolerance</th>
<th>SEE tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS139RH/Intersil</td>
<td>300 krad</td>
<td>SET LETth&gt;20 MeV cm^2/mg</td>
</tr>
<tr>
<td>LM39AJQMLV/NSC</td>
<td>50 krad</td>
<td></td>
</tr>
<tr>
<td>139/Maxwell</td>
<td>&gt;100 krad depending upon orbit and space mission</td>
<td>SEL LETth&gt;59.8 MeV cm^2/mg</td>
</tr>
</tbody>
</table>

NSC low dose rate test data

NSC 50 krad radiation tolerant

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pre irradiation limit</th>
<th>Post irradiation limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vio</td>
<td>+/- 2 mV</td>
<td>+/- 2.5 mV</td>
</tr>
<tr>
<td>Ili</td>
<td>100 nA</td>
<td>110 nA</td>
</tr>
<tr>
<td>trLH</td>
<td>0.8 ns</td>
<td>0.9 ns</td>
</tr>
</tbody>
</table>

After NAVSEA/CRANE test report, 2002

Example: Op-Amp

- RH1056 Linear Tech.
- 100 krad TID tolerant by Manufacturer
- Functional failure Between 50 and 70 krad 200 MeV protons

- Need to be cautious when selecting bipolar devices planned employed in proton rich environments (e.g. MEO)
  - The above image illustrates a Rad Hard op-amp that is functional up to almost 1 Mrad
  - However, a catastrophic failure is observed after exposure to 50 to 70 krad 200 MeV protons
Example:

Not a rad-hard or rad-tolerant device

![Graph showing change in output voltage vs. dose](image)

LM117 National
- Functional up to 100krad
- Out of spec after 60krad 50MeV protons

Sources of Radiation Data

- In house data from previous projects
- Available databases:
  - ESA: [http://escies.org](http://escies.org)
  - DTRA ERRIC: [http://erric.dasiac.com](http://erric.dasiac.com)
- Other sources of radiation data:
  - IEEE NSREC Data Workshop, IEEE Trans. On Nuc. Sci., RADECS proceedings...
  - Vendor data

Stacked devices and hybrids can present a unique challenge.
Data Search and Definition of Data Usability Flow

After K. LaBel, IEEE TNS vol 45-6, 1998

TID / DD - Analysis Flow
**Design Margin Breakpoint (DMBP)**

DMBP

DM < 1-2 < DM < 10 < DM < 100 < DM

<table>
<thead>
<tr>
<th>Hardness</th>
<th>Unacceptable</th>
<th>Critical-HCC1</th>
<th>Critical-HCC2</th>
<th>Non-Critical</th>
</tr>
</thead>
</table>

- Radiation Lot Testing

Qualitative approach recommended for systems with moderate requirements

After MIL-HDBK814

---

**Part Categorization Criteria (PCC)**

Log normal distribution law

PCC = \( \exp(K_{TLS}) \)

- \( K_{TLS} \): One sided tolerance factor based on sample size \( n \), confidence level \( C \) and probability of survival \( P_s \)
- \( s \): standard deviation of sample data

DM < 1-2 < DM < PCC < DM

<table>
<thead>
<tr>
<th>Hardness</th>
<th>Unacceptable</th>
<th>Critical</th>
<th>Non-Critical</th>
</tr>
</thead>
</table>

After MIL-HDBK-814
One-Sided Tolerance Limits, $K_{TI}$, for 90% Confidence

![Graph showing one-sided tolerance limits](image)

After R. Pease, Rad Phys Chem 43, 1994

TID analysis - Example of Application

![Graph showing TID analysis](image)

Data after Astrium test report, 1997
TID Mitigation

- Reduce the dose levels
  - Improve the accuracy of the dose level calculation
  - Change the electronic board, electronic box layout
  - Add shielding
    - Box shielding
    - Spot shielding
- Increase the failure level
  - Test in the application conditions
  - Test at low dose rate (CMOS only)
  - Tolerant designs (cold redundancies, etc.)
  - Relax the functional requirements

TID Mitigation - Examples

- TMS320C25 Texas Instruments – LEO polar
  - TID soft: 3 krad(Si) (functional failure)
  - Duty cycle in the application: 10% on
  - TID tolerance with application duty cycle: 10 krad
    The device has operated flawlessly during the mission
- FPGA 1280 ACTEL - GEO
  - TID soft: 3 krad functional at high dose rate.
  - TID at 1 rad/h: ~ 14 krad functional, 50 mA power consumption increase (max design value) after 8 krad.
  - Spot shielding with Ta: received dose = 4 krad

EADS-Astrium data
### SEE - Analysis Requirement

<table>
<thead>
<tr>
<th>SEE LET Threshold</th>
<th>Analysis Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 75 MeVcm²/mg</td>
<td>SEE risk negligible, no further analysis needed</td>
</tr>
<tr>
<td>15 MeVcm²/mg &lt; LET_{threshold} &lt; 80 MeVcm²/mg</td>
<td>SEE risk, heavy ion induced SEE rates to be analyzed</td>
</tr>
<tr>
<td>LET_{threshold} &lt; 15 MeVcm²/mg</td>
<td>SEE risk high, heavy ion and proton induced SEE rates to be analyzed</td>
</tr>
</tbody>
</table>

### SEE - Analysis Flow

1. **Mission Requirements**
   - **Radiation Environment Prediction**
     - SEE Rate Prediction
   - **Part SEE Sensitivity**
     - **SEE Criticality Analysis**
     - Functional SEE Requirements
   - Decision Tree Analysis
SEE Criticality Analysis (SEECA)
Leads to System Performance

SEE - Decision Tree

From SEECA document NASA-GSFC radhome web page
http://radhome.gsfc.nasa.gov

From SEECA document NASA-GSFC radhome web page
http://radhome.gsfc.nasa.gov
Component Characterization and Testing
TID and Displacement Damage

Motivation

• Need to know: how to do device testing
• Need to know: how to interpret existing test data
  – is it relevant to the mission environment and operating conditions?
  – have the right parameters been measured?
• What can be improved? lessons learned
  – new devices can have new (and often complex) failure modes
  – development / improvement of standard test methods
Overview

• Before the test: planning
  – difficulties with standard test methods (for DD)
  – test facilities
  – technical issues
    • choice of radiation source (particle type and energy for DD)
    • irradiation conditions (biasing etc)
    • choice of dose, dose rate, fluence, irradiation steps, annealing

• At the test
  – test set up
  – dosimetry
  – safety
  – post irradiation measurements, return of samples

• After the test: data analysis
  – prediction (e.g. for on-orbit)
Test Planning: standards

- The ESCC Basic Specification 22900 mainly concerned with TID testing but general provisions (test conditions, dosimetry, reporting) are applicable also for DD.
- For TID other standards are available such as:
  - MIL-STD-883, method 1019.7, Ionizing Radiation (Total Dose) Test Method
- For DD definition of standard test methods is difficult because:
  - effects are application specific (depend on operating conditions)
  - annealing effects (particularly, LEDs, laser diodes, optocouplers)
  - complex degradation modes (particularly detector arrays)
- Some ASTM standards are useful for neutron testing (MIL STD 883, method 1017.2):
  - E798-96 Standard practice for conducting irradiations at accelerator-based sources
  - F1190-99 Standard guide for neutron irradiation of unbiased electronic components
  - F980M-96 Standard guide for measurement of rapid annealing of neutron-induced displacement damage in silicon semiconductor devices
- Test programme will need to be tailored to requirements

Test Plan: ESCC 22900

Test plan needs to specify:
- radiation facility
- number and type of devices to be tested
- for TID dose and dose rate
- for DD beam energy and flux
- irradiation steps
- irradiation conditions for devices bias/clocking
- temperature
- annealing
- etc.
TID Test Facility
ESTEC 2000 Ci Co-60 facility. ESA

European Test Facilities - Protons

Paul Scherrer Institute, Switzerland  http://pif.web.psi.ch/

Low energy PIF
- Energy range: 6 to 70 MeV
- Proton flux: <5 \times 10^8 p/cm^2/sec
- Beam spot: circle, up to 9 cm diameter,
- Beam uniformity: > 90% over 5 cm diameter

High energy PIF
- Initial proton energies: 300, 254, 212, 150, 102 and 60 MeV.
- Energies available with PIF degrader: quasi continuously from 35 MeV up to 300 MeV
- Gaussian-form initial beam profiles with minimum FWHM=6 cm. (Can be flattened)
- The maximum diameter of the irradiated area: \phi 9 cm.
- Neutron background: less than 10^{-4} neutrons/proton/cm^2.

CYCLONE, Universite catholique de Louvain, Louvain-la-Neuve, Belgium
www.cyc.ucl.ac.be

Proton beam line (LIF)
- 10 to 75 MeV, either by cyclotron adjustment or using plastic degrader
- 10% uniformity over 10 cm diameter
- neutron fluence/proton fluence 1-5E-4 (depending on neutron energy)
TID choice of radiation source

Available radiation sources

- Gamma rays
  - Co-60. Energy 1.173 MeV, 1332 MeV
  - Cs-137. Energy 0.662 MeV
  - Most commonly used
- X-rays. Electrons bombarding W, Cu
  - Tungsten 59.3 keV, Copper 8.04 keV
- Electron Beams
  - Van-de-Graaff (0.1 - 10 MeV)
  - Linac (4 - 40 MeV)
  - High dose rate
  - Non-encapsulated devices
- Protons > 10 MeV
  - Useful for Optoelectronic Devices

DD, Choice of Particle Type and Energy

- 50 - 60 MeV is a good proton test energy
  - particularly for GaAs devices (NIEL scaling uncertain)
    - there is a case for using < 30 MeV because of NIEL uncertainties
    - also good penetration depth (> 10 mm Al), but masking difficult
- 10 MeV also a good energy
  - can mask using thin (1.5 mm) Al plates
  - comparison with existing data
- For solar cells the shielding is reduced and most of the damage comes from low energy protons and electrons
  - 1-3 MeV electrons and 3 - 10 MeV protons are common
  - dependence on NIEL is different for electrons and protons, advisable to do separate tests
- Always ideal to test at several energies - but not always practical (e.g. funding issues)
  - Note protons result in both TID and DD. To separate these effects testing of devices both with gamma and protons may be necessary.
Number of devices/dose (fluence) steps/dose rate (flux)

- Number of test devices needs to be sufficient to cover the number of dose (fluence) steps, bias conditions and annealing tests.
  - number of irradiation steps depends on whether a general evaluation or specific for a project
    - for imager arrays can reduce by masking the device into several fluence regions
  - for projects, dose (fluence) should be derived from environment document (including margins). *For space projects can use SPENVIS.*
  - some device types show significant device-to-device variations so need to increase the number of devices (e.g. to ~10) to get good statistics
    - e.g. for TID (ELDRS tests) for DD (LEDs, VCSELs, optocouplers)
- Devices not biased for DD tests however, important for TID tests.
  - no evidence for flux rate effects for DD however, dose rate important for bipolar type devices

Practical issues to be considered

- Investigate number of devices that may be tested at the same time (beam uniformity, masking)
- Cables/feed-throughs
  - air or vacuum irradiation (for < 20 MeV protons)
  - check pin-out of feed-through connectors (*e.g. 1-1 connectors*)
  - consider noise induced by long cables (proton facilities are “noisy”)
- For DD heavy metals become activated
  - affects timescales for device interchange and *return to the lab*
  - use low density materials where possible
    - foam rather than sockets for shorting
    - former materials for fibre optics
  - nearby materials affect neutron environment (reflections etc)
- Investigate possibility of performing most measurements (intermediate) at facility (save time and costs)
Before the Test

- **Booking beam time**
  - allow time for device interchange, calibration, outages etc
  - purchase order

- **Customs formalities & insurance**

- **Arrangements for return of samples (activation)**

- **Parts labeling, for DD possible de-lidding**

- **Pre-irradiation measurements**
  - preparation of test sheets

At the Test

- **Pre-checkout of equipment**

- **Shielding of equipment (if needed)**
  - For DD, secondary neutron environment
    - hydrogen (polyethylene, polypropylene) as a moderator (slowing to thermal velocities)
    - boron as an absorber of thermal neutrons (load with borax)

- **Record keeping** *(radiation steps, sample geometry etc)*

- **Safety**
  - can’t be in beam area when beam is on - interlocks etc.
  - rules on food and drink - dust contamination risk
  - interchange of samples – for DD, activation risk - time limits
  - local procedures - personal dosimeters, training etc.
At the Test - Dosimetry

- Usually done by facility staff and accurate to ~ ±5% to ±10%
  - ion chambers (TID, DD)
  - faraday cup (DD)
  - plastic scintillators (DD)
  - secondary electron monitors (DD)
  - radiographic plastic films (DD)
    - e.g. for beam uniformity measurement
  - silicon surface barrier detectors (TID, DD)
  - activation foils (DD)
    - for measuring neutron energy spectrum
  - Geiger-müller, (TID)
  - Termo-luminescent dosimeters (TID)

- Dosimetry is important and human errors can occur!
  - Take care
  - Possibly dosimetry performed by customer (bring reference dosimeter)
  - Spare devices can be useful if re-test needed

Post Irradiation Measurements

- **Aim is to determine damage constants, $k_{\text{damage}}$**
  - depend on parameter measured and on conditions
    - temperature, bias etc
- May need specialized equipment (testing at facility)
  - can’t always do in situ, or within 1 hour
  - usually OK, as long as annealing is considered
- For DD often some prompt annealing (first few minutes)
  - maybe also some minor changes over the first few days or weeks (so recommend wait > 2 days)
- Recombination-enhanced annealing (LEDs etc)
- High temperature anneals
- First level analysis in real time
After the Test

• Test report - gives details of
  – irradiation facility & operating mode, dosimetry
  – device details: manufacturer, date code etc
  – irradiations, time, temperature, fluence etc
  – test results, including annealing

• Prediction for mission environment

  **DD**: $\text{parameter damage} = k_{\text{damage}} \times \text{displacement damage dose}$

  **TID**: $\text{parameter damage} = k_{\text{damage}} \times \text{dose}$

  – Bear in mind limitations to NIEL scaling

Summary

• **Successful device testing requires careful planning**
  – choice of source, particle type and energy, dose, fluence
  – choice of device operating conditions
  – device mounting
  – irradiation and annealing steps
  – measuring the right parameters

• **As well as accurate dosimetry**

• **Accurate reporting and effects prediction**
  – sharing the data and making it publicly available
Component Characterisation and Testing
Single Event Effects

Designing and conducting an SEE experiment

**Goal of a SEE experiment**

- Providing good data for SEE rate prediction
- **cross-section curve**
- Define safe operation limits (SEB, SEGR) : derating
- **maximum bias conditions** (threshold \( V_{DS} \) for failure)

- real-time testing
- functional testing
- SEU, MBU, SEFI, SHE, SED
- \( I_{CC} / I_{DS} \) monitoring
- SEL, SESB, SEGR, SEB, SET

exposures to beams with known characteristics

\[ \Rightarrow \text{particle accelerators} \]
Standard test methods and guidelines

**Dosimetry**:  
- energy ±10%  
- flux uniformity ±10% over the device area  
- counting ±10%  

**Irradiation conditions**:  
- heavy ion  
  - range ≥ 40µm, LET max  
  - 10² ≥ flux ≥ 10² ions/cm².s  
  - tilt angles limited to 60°  
- proton  
  - 20 - 300 MeV  
  - 10³ ≥ flux ≥ 10⁸ p./cm².s  
  - normal incidence exposures  

\(\text{LET max} : \text{allows } \sigma_{\text{sat}} \text{ to be measured (SEE "soft/robust" device)}\)

\(\text{flux} : \text{depends on tester capabilities, test completeness within reasonable time}\)

\(\Delta \text{tilt} : \text{tilt dependence with proton?}\)
Standard test methods and guidelines

**Testing requirements**
- Sample size ≥ 3 (same date-code) adjustable
- 5 measurements at different LETeff (HI) or energies (p+)
- Fluence max (10^7 & 10^10 part./cm².s for HI and p+) or a meaningful number of events

Sample size: must be adapted according to the class of event (destructive) and the sensitivity of the device (SEE robust devices, TiD soft devices)

* n numerous parts in flight & resistant devices

Minimum set of data: depends on the test objective
End of test criterion: accurate measurement…… or TiD degradation

**Test report**
- Device tested
- Test setup and methods
- Bias and ambient conditions
- Results

Ground-based test facilities

*Main accelerators*

1st order concerns in selecting the beams:
- LET/Range parameters for heavy ion testing
  - LET: [1-80 MeV/mg.cm²]
  - Range ≥ 30µm (the larger the better!)
- Energy in case of proton testing (10 - 300 MeV)

<table>
<thead>
<tr>
<th>Heavy Ion Testing</th>
<th>Main Accelerators</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI : E &lt;&lt; 10 MeV/n (Tandem Van de Graaff)</td>
<td>France: IPN, Italy: LNL, UK: AEA Harwell, USA: BNL, …</td>
</tr>
<tr>
<td>HI : E ≥ 10 MeV/n p+: tens of MeV (cyclotrons)</td>
<td>Belgium: UCL (HIF), Finland: JYFL, Japan: TIARA, Switzerland: PSI (OPTIS), USA: LBL, UCD…</td>
</tr>
<tr>
<td>HI : up to 1GeV/n p+: hundreds of MeV (cyclotrons, synchrotrons)</td>
<td>Canada: TRIUMF, France: GANIL, Germany: GSI, Japan: JAERI, Switzerland: PSI (PIF), CERN, Russia: DUBNA, PNPI, USA: IUCF, NSCL, TASCC, TAMU…</td>
</tr>
</tbody>
</table>
Critical elements to be considered

SEE testing is highly individualised
- wide range of devices (architecture, technology) and responses
- specific application requirements
- unexpected on-line results

several test protocols depending on the type of device and event
- configuration
- operational mode
- clock rate
- test pattern
- electrical bias
- output load
- duty factor.....

Specific test requirements with accelerator

camera / light
shutter / counting

DUT

electrical noise

pumping

vacuum chamber
(T°, "long" cables)

"de-lidded" part

Tester
remote testing

costly and limited availability: test plan, 1st level results' interpretation in real time
Data representativeness (1)

*the natural space environment*  *the simulated environment*
large distribution of ion species  use of
“standard” beams
high energies  “low” energies
omnidirectional flux  limited range of incidence
combined environment

![Graph showing the relationship between LET and E (MeV/n) for different elements.](image)

- $^{1}$H
- $^{12}$C
- $^{28}$Si
- $^{56}$Fe
- $^{84}$Kr

Data representativeness (2)

*Range effects*

charge collection over long distances (MBU, SEL, SET, SEB)  Backside irradiation

- **SEUs in SDRAM**

![Graph showing X-section vs. LET for SEL: LTC1851.](image)

- **SEL: LTC1851**
- after [Bea03]
Influence of experimental conditions (1)

Operating conditions (configuration, operating mode, clock rate, pattern, bias, output load, duty factor, etc.)

Worst-case conditions representative of the nominal system operating conditions

Influence of testing conditions (2)

SET in comparators

Power supply $\delta V_{\text{input}}$

Output load

Output Voltage (V)

$R_{\text{pull-up}}=5\,\text{k}\Omega$

$R_{\text{pull-up}}=2.5\,\text{k}\Omega$

Time (s)

% rail to rail transients

After [Pos03]

X-section (cm$^2$)

LET (MeV/mg.cm$^2$)

$0.05\,\text{V}$

$0.1\,\text{V}$

$0.8\,\text{V}$

$1\,\text{V}$

$2\,\text{V}$

0E+0 2E-6 4E-6 6E-6 8E-6

0 2 4 6

4 2 0 -2 -4

6E-7 1E-7 1E-6 1E-5 1E-4 1E-3

0 20 40 60

< 0.7 0.8 0.9 1
Influence of testing conditions (3)

- Increasing speed
- Downscaling
- Lower Vcc

SET in logic/digital devices

Node sensitivity => bias, load, bias, LET
Transient feature => clock rate
Time of ion strike => transient, design
Propagating path => design
dynamics of the latch =>

Soft fault?

Operating mode

SEU

CS (frequency)

No saturation CS(LET)

Interpretation of generated data

Protons

2-parameter Bendel model

\[ \sigma = 10^{-12} \left( \frac{B}{A} \right)^2 \left( 1 - \exp(0.18 \sqrt{Y}) \right) \]

with \( Y = \sqrt{\frac{18}{A}} \cdot (E - A) \)

- \( E \): Proton energy (MeV)
- \( A \) and \( B \) derived from data (MeV)
In-Flight Anomaly


FOTON M2 was launched from Baikonor Cosmodrome, Kazakhstan on 31 May 2005.
# Spend 15.6 days in Earth orbit at 280/305 Km, at 63° inclination.
# Lid opened at the beginning of the 3rd orbit.
# For the FOTON-M2 mission, the BIOPAN facility has had some internal modifications inc. – a new microcontroller for more efficient data handling.
# Biopan failed in the 5th orbit (total orbits 253)
In-Flight Anomaly

- BIOPAN post flight Failure Analysis
- Used microcontroller board (commercial) – Cygnal C8051F124.
- This board was found in a condition that not allowed data retrieval.
- High current consumption.
- Non destructive latch-up event on one or more SRAM modules occurred during the mission.
- A latch-up condition in SRAM #4 was concluded as the possible cause.
- This failure condition was reproduced using a spare microcontroller board.
- The SEL failed 1M8 bit SRAM was from Brilliance Semiconductor Inc.
  marked: BS62LV8003EI_70 (3.3 V).

Standards

- Environment
  - ECSS-E-10-04, Space Environment
  - ECSS-E-10-12, Methods for Calculation of Radiation Received and its Effects, and a Policy for Design Margin
- TID
  - ESCC 22900, Total Dose Steady-State Irradiation Test Method
  - MIL-STD-883, method 1019.7, Ionizing Radiation (Total Dose) Test Method
- DD
  - MIL-STD-883, method 1017.2, Neutron Irradiation
- SEE
  - ESCC 25100, Single Event Effects Test Method and Guidelines
  - ASTM F1192-00, Standard Guide for the Measurement of Single Event Phenomena (SEP) Induced by Heavy Ion Irradiation of Semiconductor Devices
  - JEDEC JESD57, Test Procedures for the Measurement of Single Event Effects in Semiconductor Devices from Heavy Ion Irradiation

ESCC: https://escies.org/ReadArticle?docId=148
ECSS: http://www.ecss.nl/
ASTM: http://www.astm.org/
JEDEC: http://www.jedec.org/
European Space Component Information Exchange System (ESCIES)

Radiation

ESCIES Radiation

Due to the new ESCIES web page layout some links maybe broken, pages missing and some text is incorrect. We hope to resolve all these problems as soon as possible and user feedback will assist us. So please inform the webmaster of any problems you encounter. Thank you in advance for your understanding and assistance.

- General Information
- Radiation Database
- Standards
- Radiation Test Facilities
- Facility Responders
- Radiation Environment Monitoring Instruments
- Radiation Evaluation of DDR / DDR3 SRAM Memories
- Study, Conference & Other Papers
- RADAC Thrust Workshop on European SEE Accelerators
- QCA Final Participation Days
- Conference & Course Announcements
- RADAC 2093
- Links to Dose Rate Calculator and External Sites
- Contacts
ESCIES Radiation

ESCA Radiation Facilities Schedules

External Facilities Schedules

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<th>Schedule</th>
<th>Contact for ESA bookings</th>
<th>Contact for Non-ESA bookings</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIF</td>
<td>Remon</td>
<td>René Sörensen</td>
<td>Kim Reger</td>
</tr>
<tr>
<td>PIF / OPTIS Schedule</td>
<td>Remon</td>
<td>René Sörensen</td>
<td>Willem Hennar</td>
</tr>
<tr>
<td>RADEF</td>
<td>Borell</td>
<td>René Sörensen</td>
<td>Ari Hyyrinen</td>
</tr>
</tbody>
</table>

ESTEC Co60 Facility

- Facility Available for Booking during weekdays
- Facility Available for Booking during weekdays - Background tests running in parasitic mode
- Facility partially reserved
- Facility Reserved
- Public Holiday or Facility not available - only background tests running

<table>
<thead>
<tr>
<th>August 07</th>
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<tbody>
<tr>
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<td>20</td>
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</tbody>
</table>

ESA and ESA supported European Component Irradiation Test Facilities
ESA and ESA supported European Component Irradiation Test Facilities

- ESTEC 60Co facility
- ESTEC CASE (Cf-252)
- PIF Proton Irradiation Facility, Paul Scherrer Institut (PSI), Switzerland.
- HIF Heavy-ion Irradiation Facility – UCL, Belgium.
- LIF Light-ion Irradiation Facility – UCL, Belgium.
- NIF Neutron Irradiation Facility – UCL, Belgium.
- RADEF RADiation Effects Facility – Jyväskylä, Finland.
- SEREL2 Picosecond Laser Facility – MBDA, UK. (Under ESA contract investigating utilisation of pulsed lasers for SEE testing)

Final Thoughts / Mitigation

- TID / DD
  - Additional shielding (more effective for TID and electron radiation. Be aware of secondaries for DD)
  - Ample derating
  - Robust electronics (e.g. for DD, anticipate drift and bias accordingly)

- SEE
  - Shielding not very effective
  - Implement autonomous functions such as rebooting
  - Employ Error detection and correction for critical components
  - If absolutely necessary employ latch-up protection (LP) however consider TID induced increased power consumption. Do not employ LP for critical components.
  - Analyze transient effects in a system early in the system design. Ensure, system not sensitive to transients.
  - Employ fault tolerant design

From L. Adams, radiation training course may 2003
Final Thoughts / COTS

- Why use
  - Complexity of function
  - Performance
  - Availability
- Drawback
  - Little or no traceability
  - Rapid and un-announced design and process changes
  - Rapid obsolescence
  - Packaging issues (plastic)
    - Effects of burn-in on radiation effects
    - Deep dielectric charging in space
- Use of COTS
  - The use of COTS does NOT necessarily result in cost saving
  - Cost of ownership is the important consideration
  - First choice should always be space qualified or QML if available
  - A great deal of knowledge available for some components (a little more expensive). Preferable to standardize on these components (do not always be seduced by newer technologies, more complexity, better performance … )

From L. Adams, radiation training course May 2003

---

Final Thoughts / Risk Assessment & Mitigation

- Apply sufficient radiation margin
- Fully characterize key technologies
- Limit the use of new technologies (know what you are flying)
- Eliminate or mitigate for new technologies (e.g. shielding)
- Maintain awareness of developments in radiation effects
- Do not cut back on testing (if planned well resources and costs required for testing are not excessive)
- Look for system solutions

From L. Adams, radiation training course May 2003
Final Thoughts / RHA

• The RHA approach on space systems is based on risk management and not on risk avoidance.
• The RHA process is not confined to the part level:
  – Spacecraft layout
  – System/subsystem/circuit design
  – System requirements and system operations
• RHA shall be taken into account in the early phases of a program development, including the proposal and feasibility analysis phases.