
Jean-Marie Lauenstein, NASA/GSFC
List of Acronyms

ASTM – (no longer an acronym)
DLA – Defense Logistics Agency
GSFC – Goddard Space Flight Center
IC – Integrated Circuit
JEDEC – (no longer an acronym)
JESD – JEDEC Standard
JPL – Jet Propulsion Laboratory
LET – Linear Energy Transfer
MBU – Multiple Bit Upset
MCU – Multiple Cell Upset
MIL-STD – US Military Standard
MOSFET – Metal Oxide Semiconductor Field Effect Transistor
NEPP – NASA Electronic Parts and Packaging program
SBU – Single Bit Upset
SEB – Single-Event Burnout
SEE – Single-Event Effect
SEFI – Single-Event Functional Interrupt
SEGR – Single-Event Gate Rupture
SEU – Single-Event Upset
SET – Single-Event Transient
SOA – Safe Operating Area
TM – Test Method
XS – Cross Section

Outline

• Test Standards & Guidelines: Putting JESD57 into Context
• Motivation for Update
• Revision Highlights
• Challenge of New Technology
• Conclusions
Standard Rationale

• Standards & Guidelines are developed/revised to:
  – Ensure tests follow best practices
  – Ensure results from different vendors/testers are comparable
  – Minimize and bound systematic and random errors

Data must be meaningful and must facilitate part selection and risk analysis

Best practices must be disseminated to new members of the test community
# Key Space Radiation Test Standards

<table>
<thead>
<tr>
<th>Standard</th>
<th>Title</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>JEDEC JESD57</td>
<td>Test Procedures for the Measurement of SEE in Semiconductor Devices from Heavy-Ion Irradiation</td>
<td>1996</td>
</tr>
<tr>
<td>JEDEC JESD234</td>
<td>Test Standard for the Measurement of Proton Radiation SEE in Electronic Devices</td>
<td>2013</td>
</tr>
<tr>
<td></td>
<td>TM 1017: Neutron irradiation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TM 1019: Steady-state total dose irradiation procedure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TM 1080: SEB and SEGR</td>
<td></td>
</tr>
<tr>
<td>MIL-STD-883</td>
<td>Microcircuits</td>
<td>2014</td>
</tr>
<tr>
<td></td>
<td>TM 1017: Neutron irradiation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TM 1019: Ionizing radiation (total dose) test procedure</td>
<td></td>
</tr>
<tr>
<td>ESA-ESCC-25100</td>
<td>SEE Test Method and Guidelines</td>
<td>2014</td>
</tr>
<tr>
<td>ESA-ESCC-22900</td>
<td>Total Dose Steady-state Irradiation Test Method</td>
<td>2010</td>
</tr>
</tbody>
</table>

(Prompt dose and terrestrial radiation standards not included)

*TM = Test Method*
## Key Space Radiation Test Standards

<table>
<thead>
<tr>
<th>Standard</th>
<th>Title</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>JEDEC JESD57</td>
<td>Test Procedures for the Measurement of SEE in Semiconductor Devices from Heavy-Ion Irradiation</td>
<td>1996</td>
</tr>
<tr>
<td>JEDEC JESD234</td>
<td>Test Standard for the Measurement of Proton Radiation SEE in Electronic Devices</td>
<td>2013</td>
</tr>
</tbody>
</table>
| MIL-STD-750-1| Environmental Test Methods for Semiconductor Devices  
TM 1017: Neutron irradiation  
TM 1019: Steady-state total dose irradiation procedure  
TM 1080: SEB and SEGR | 2014  |
| MIL-STD-883  | Microcircuits  
TM 1017: Neutron irradiation  
TM 1019: Ionizing radiation (total dose) test procedure | 2014  |
| ESA-ESCC-25100| SEE Test Method and Guidelines | 2014  |
| ESA-ESCC-22900| Total Dose Steady-state Irradiation Test Method | 2010  |

(Prompt dose and terrestrial radiation standards not included)

*TM = Test Method*
# Key Space Radiation Test Standards

<table>
<thead>
<tr>
<th>Standard</th>
<th>Title</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>JEDEC JESD57</td>
<td>Test Procedures for the Measurement of SEE in Semiconductor Devices from Heavy-Ion Irradiation</td>
<td>1996</td>
</tr>
<tr>
<td>JEDEC JESD234</td>
<td>Test Standard for the Measurement of Proton Radiation SEE in Electronic Devices</td>
<td>2013</td>
</tr>
<tr>
<td></td>
<td>TM 1017: Neutron irradiation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TM 1019: Steady-state total dose irradiation procedure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TM 1080: SEB and SEGR</td>
<td></td>
</tr>
<tr>
<td>MIL-STD-883</td>
<td>Microcircuits</td>
<td>2014</td>
</tr>
<tr>
<td></td>
<td>TM 1017: Neutron irradiation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TM 1019: Ionizing radiation (total dose) test procedure</td>
<td></td>
</tr>
<tr>
<td>ESA-ESCC-25100</td>
<td>SEE Test Method and Guidelines</td>
<td>2014</td>
</tr>
<tr>
<td>ESA-ESCC-22900</td>
<td>Total Dose Steady-state Irradiation Test Method</td>
<td>2010</td>
</tr>
</tbody>
</table>

(Prompt dose and terrestrial radiation standards not included)

*TM = Test Method*
# Space Radiation Test Guidelines

<table>
<thead>
<tr>
<th>Standard</th>
<th>Title</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM F1190</td>
<td>Practice for the Neutron Irradiation of Unbiased Electronic Components</td>
<td>2011</td>
</tr>
<tr>
<td>MIL-HDBK-814</td>
<td>Ionizing Dose and Neutron Hardness Assurance Guidelines for Microcircuits and Semiconductor Devices</td>
<td>1994</td>
</tr>
<tr>
<td>SAND 2008-6983P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAND 2008-6851P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NASA/ DTRA</td>
<td>Field Programmable Gate Array (FPGA) Single Event Effect (SEE) Radiation Testing</td>
<td>2012</td>
</tr>
</tbody>
</table>

(See ASTM website for additional guidelines)

Motivation for JESD57 Update

• **Review cycle for JESD57 is overdue**
  – Outdated elements include, among others, facility capabilities, beam angle of incidence methods and objectives, and even some of the definitions of various SEE.
  – Missing elements include:
    • “Modern” complex device test considerations
    • Single-event burnout testing
    • Single-event transient testing

Higher-energy (> 10 MeV/u) facilities explicitly NOT included in 1996 JESD57

Angle tests not just for effective LET: critical to reveal some SEE. Both tilt and roll angles can matter.

Tipton, IEEE TNS, 2008

http://cyclotron.tamu.edu/ref/in_air.php
Motivation for JESD57 Update

• Review cycle for JESD57 overdue
  – Outdated elements include, among others, facility capabilities, beam angle of incidence methods and objectives, and even some of the definitions of various SEE.
  – Missing elements include:
    • “Modern” complex device test considerations
    • Single-event burnout testing
    • Single-event transient testing

• JESD57 SEGR method no longer in line with MIL-STD-750 TM1080
    • LET metric was expanded to emphasize the impact of ion species & energy on SEGR susceptibility
    • Worst-case penetration range defined as yielding max energy deposition in the epilayer

Ion range matters for SEGR: LET too simplistic as a single metric

MIL-STD-750F

Titus, SEE Symp., 2011
Motivation for JESD57 Update

• Review cycle for JESD57 overdue
  – Outdated elements include, among others, facility capabilities, beam angle of incidence methods and objectives, and even some of the definitions of various SEE.
  – Missing elements include:
    • “Modern” complex device test considerations
    • Single-event burnout testing
    • Single-event transient testing

• JESD57 SEGR method no longer in line with MIL-STD-750 TM1080
    • LET metric was expanded to emphasize the impact of ion species & energy on SEGR susceptibility
    • Worst-case penetration range defined as yielding max energy deposition in the epilayer

• Update to JESD57 can form basis for DLA integration of SEGR/SEB test method into MIL-STD-883, “Microcircuits”
  – Both current JESD57 and MIL-STD-750 TM1080 standardize testing of discrete, planar-gate vertical power MOSFETs
  – Other discrete topologies and integrated components not explicitly addressed
Revision Highlights: Format

1996 JESD57

Scope → Terminology

Procedures
• Test plan
• Pre-test prep
• Dosimetry
• Testing procedure

SEGR Test
• Scope
• Referenced documents
• Terminology
• ...

Final Report

Draft Revision

Scope → Normative References

Terms & Definitions → Beam Dosimetry

Test Plan → Pretest Procedures

Testing Procedures
• General overview
• Setup procedure
• Operating procedure – SEE XS curve data collection
• Operating procedure – SEGR/SEB SOA data collection
• Operating procedure – SET characterization

Final Report

Revision Highlights: Definitions

• Many terms added to definitions section:
  – Bragg curve, Bragg peak;
  – Multiple-bit upset; multiple-cell upset
  – SEGR Post-irradiation gate stress (PIGS) test
  – Single-event transient
  – Stuck bit

• Many definitions updated
  – Effort to stay consistent with other JEDEC documents:
    • JESD88, “JEDEC Dictionary of Terms for Solid-State Technology”
    • JESD89-1A, “Test Method for Real-Time Soft Error Rate”
      – Including current draft revision
  – Despite this effort, some definition revisions are new and will require JEDEC approval/adoptions
Terms & Definitions Highlight: Single-Event Functional Interrupt (SEFI)

• 1996:

The loss of functionality of the device that does not require cycling of the device's power to restore operability unlike SEL and does not result in permanent damage as in SEB.

NOTE — SEFI is typically caused by a device being cycled to a nongenerated test mode due to a heavy ion strike.

• Draft Revision:

A non-destructive interruption resulting from a single ion strike that causes the component to reset, hang, or enter a different operating condition or test mode.

NOTE 1  A SEFI is often associated with an SBU/MBU in a control bit or register.

NOTE 2  Changes in functionality may require a soft or hard reset of the device, reprogramming of the control registers, or power cycling.

NOTE 3  A SEFI can introduce a latent reliability issue due to a period of high current. SEFIs that result in permanent damage are designated as single-event hard errors.
Terms & Definitions Highlight: 
Single-Event Upset (SEU)

• **1996:**

A single latched logic state from one to zero, or vice versa.  
NOTE The SEU is “soft” because the latch can be rewritten and behave normally thereafter.

• **Proposed:**

The change of a bi-stable node state from one to zero, or vice versa, due to the passage of a single energetic particle.  
NOTE 1 SEU, including SBU, MBU, and MCU, is typically "soft" because the affected nodes can be rewritten and behave normally thereafter.  
NOTE 2 An SEU that results in a change in device functionality requiring intervention is defined instead as a SEFI.
Revision Highlights: Expansion of SEE Test Procedures

- **SEB & SEGR:**
  - SEB test procedure added;
  - SEGR & SEB procedures expanded to include both devices and integrated circuits (ICs)
    - Accounts for inaccessible drain and/or gate nodes in ICs

- **SET:**
  - New test procedure for characterizing SETs in analog parts
    - SET magnitude/duration plots
    - SET cross-section vs. LET for rate determination
  - Digital SETs out of scope for this revision
    - References provided instead.

JESD57 Challenge: Advanced Electronics

• How do we incorporate advanced electronics SEE testing into SEE test standards?
  – Revision of JESD57 is an opportunity for inclusion of more established methods for testing advanced electronics
  – Highly complex technologies will benefit from specific guidelines
    • ex/ NASA FPGA test guideline
  – Complex devices incorporate many modes and functions
    • Test results depend on how we test the device
    • The bleeding edge of testing is generalizing application specific test results to bound flight performance at all stages of the mission

High-Speed Test Fixture

Photo credit: J. A. Pellish, 2013
The Time Lag

- Test standards & guidelines can (and often do) take years to develop or revise
  - Widespread compliance can take additional years
- Technology & research continuously evolve

The time lag is both useful and problematic
JESD57 and Test Guidelines

• Draft Revision of JESD57 = True “Test Standard”
  – Guideline material not permitted and thus removed
• “Informative Annexes” can serve as repositories for guideline material
  – Document the “why” behind the standards
  – Allow inclusion of test considerations when methods have yet to be established
    • For new technologies
    • For new failure modes

Informative annex contains information intended only to assist the understanding or use of the document.
Summary

- JESD57 is the only U.S. test standard covering many of the heavy-ion induced single-event effects.
- Last updated in 1996, a new revision will soon be submitted for a vote.
- Advanced electronics and complex technologies present a continual challenge:
  - Solutions likely in the form of separate guidelines;
  - Informative Annexes may provide an initial step toward inclusion in JESD57.

We must recall that:

- Test standards are a compromise between technical rigor and economic realities
  - The goal is to be good enough to ensure success and cheap enough that the standards & guidelines will actually be used
JESD57 Update: The “Who”

- JESD57 ownership: JEDEC JC-13.4 Government Liaison Subcommittee on Radiation Hardness Assurance
- Committee meetings 3 times/year:
  - Both JC13.4 and G12 Radiation Hardness Assurance subcommittees have provided a platform to work with relevant industry and user communities to:
    - Review major changes in content and format
    - Work toward consensus on more controversial or less established definitions, concepts, or methods

Jean-Marie Lauenstein’s involvement in this update process is sponsored by the NASA Electronic Parts & Packaging Program.