Single Event Effects (SEE) Testing: Practical Approach to Test Plans

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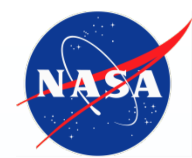
ASRC Federal Space and Defense Inc., work performed for NASA/GSFC

Unclassified

Deliverable to NASA Electronic Parts and Packaging (NEPP) Program to be published on nepp.nasa.gov originally presented by Kenneth A. LaBel at the 2014 Government Microcircuits Applications & Critical Technologies Conference (GOMAC) Tech, Charleston, SC, March 31 to April 4, 2014.

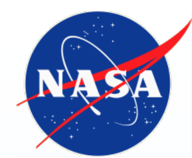
Acronyms

CM	Configuration Management
DTRA	Defense Threat Reduction Agency
DUTs	Devices Under Test
ESA	European Space Agency
FPGA	Field Programmable Gate Array
FWHM	Full Width Half Max
IO	Input/Output
LET_{th}	Linear Energy Transfer Threshold
NEPP	NASA Electronic Parts and Packaging
NSREC	Nuclear and Space Radiation Effects Conference
PEMs	Plastic Encapsulated Microcircuits
PI	Principal Investigator
POF	Physics of Failure
RADECS	Radiation Effects on Components and Systems
SEE	Single Event Effects
SEL	Single Event Latchup
SEU	Single Event Upset
SOC	Systems on a Chip
VHDL	Very High Speed Integrated Circuit (VHSIC) Hardware Description Language



Outline

- Introductory Comments
  - Abstract, motivation, and scope
- Requirements
  - Flight Projects
  - Research
  - Programmatic constraints
- Device Considerations
  - A word on data collection
- Test Set Considerations
- Facility Considerations
- Logistics
- Contingency Planning
- Test Plan Outline
- Summary



Motivation

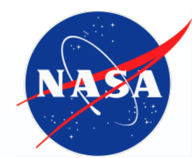
- **General guidance on performing SEE testing such as the JESD57 [1], ASTM F1192 [2], and ESA [3] documents have been in place for decades.**
- **However, little guidance exists for developing the appropriate SEE test plan.**
- **In 2011, LaBel *et al*. presented thoughts on this topic at the RADECS Conference short course [4].**
  - **Unfortunately, this is not an archival record and not widely available to the U.S. aerospace community.**
  - **We attempt to rectify that here by providing an overview of SEE test planning, with updates from the 2011 presentation.**

[1] http://www.jedec.org/standards-documents/docs/jesd-57

[2] http://www.astm.org/Standards/F1192.htm

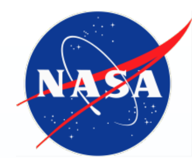
[3] https://escies.org/download/specdraftapppub?id=995 (ESCC Basic Specification No. 25100)

[4] K. A. LaBel et al., “Single Event Effect (SEE) Test planning 101,” RADECS Conf. Short Course, Seville, Spain, 2011.



Abstract

- While standards and guidelines for performing SEE testing have existed for several decades, guidance for developing SEE test plans has not been as easy to find.
- In this presentation, the variety of areas that need to be considered ranging from resource issues (funds, personnel, schedule) to extremely technical challenges (particle interaction and circuit application), shall be discussed.
- Note: we consider the approach outlined here as a “living” document:
  - Mission-specific constraints and new technology related issues always need to be taken into account.



Scope and Limitations

- This is a presentation on SEE Test Plan (or Test Planning) development.
- It is NOT:
  - How to test or testing methodology, nor,
  - A detailed discussion of technology, nor,
  - New material on new effects.
- It is:
  - An introductory discussion of the items that go into planning an SEE test that should complement the SEE test methodology used.
- Material will only cover heavy ion SEE testing and not proton, LASER, or other, although many of the discussed items may be applicable to these other test sources.

General Outline for a SEE Test Plan

- Introduction and objectives (or requirements)
- Detailed device information
- Documentation
  - Block diagrams, circuit diagrams, cabling diagrams, datasheets, etc…
  - Photos of device and test set
- Equipment list
  - Packing and shipping information
- Test methodology and data capture
  - Including Data Storage Structure
- Configuration management
  - Data backup and distribution plan
- Personnel and logistics
- Data analysis plan
- Contingency plan

SEE Test Plan Factors

- Three factors are weighed in developing the test plan:
  - Technical (all the engineering and science),
  - Programmatic (all the cost and schedule), and,
  - Logistics (all the constraints of being off-site and having appropriate documentation/configuration).
- Keeping these considerations in mind, a SEE test plan combines
  - The information ranging from requirements to
  - Resources to technical approach to
  - Post-testing analysis.
- These are the main talking points of this presentation.

Requirements – Dual and Competing Nature(s)

- Programmatic
  - Cost
  - Schedule
  - Personnel
  - Availability
  - Criticality
  - RISK!
- Technical
  - Device
  - Packaging
  - Beam/facility
  - Application
  - Data Capture

Dual Nature 2: Flight Project versus Research

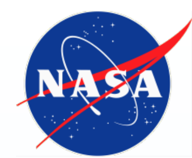
How we plan and prepare for a test will also vary with this trade space.

All tests are driven by requirements and objectives in one manner or another.

Flight Project Requirements

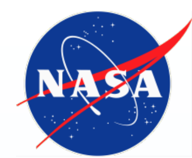
- **When planning a test for a flight project, considerations may include:**
  - **Acceptance criteria**
    - **Error or fail rate (System or Device)**
      - **System availability may be appropriate, as well**
    - **Minimum device hardness level**
      - **LET_{th}, for example**
    - **Error definition and application information**
  - **User application(s)**
    - **Circuit**
      - **We note that "test as you fly" is often recommended, but not necessarily appropriate for an accelerated beam test.**
    - **Criticality**
  - **Programmatic constraints.**
- **The bottom line is that flight project tests are usually application specific and designed to get a specific answer such as:**
  - **Is the SEL threshold higher than X? or**
  - **Will I see an effect more than once every 10 days?**

The key concept for developing the SEE test requirements is to bound the risk related to mission interruption, anomalies, or failure.



Research Requirements

- These are less specific than requirements for flight projects and may include:
  - Generic technology/device hardness or physics of failure,
  - Application range,
  - Angular exploration,
  - Frequency exploration,
  - Beam characteristics such as ion/energy/range effects,
  - Error propagation, charge sharing, etc.,
  - Circuit effects, and,
  - Test methodology evaluation.
- Programmatic constraints still need to be considered (beam time, costs, etc.).
- The bottom line is that all requirements and objectives should be “in plan,” i.e., considered prior to test and included in test plan development.

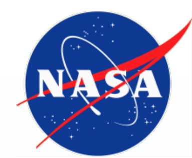


Resource Estimation

- **Many factors will weigh in to actual resource (re: cost and schedule) considerations including:**
  - Complexity of device/test and preparation thereof,
  - Facility availability (and time allotment),
  - Urgency of test, and,
  - Funds availability, and so forth.
- **It is important to remember to work with the facility of choice to get scheduled in advance – last-minute access is rare.**
- **Schedules should be developed and included that include all phases of testing from requirements definition to completed report to the customer.**
- **The next chart provides an example of cost considerations.**

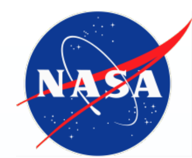
Cost Estimation Factors

- Labor
  - PI/team lead
  - Test engineers/technicians
    - Electrical, mechanical, VHDL, software, cabling, etc.
  - Test set verification and debugging
  - Test performance (pay attention to overtime needs)
  - Data analysis
  - Report and plan writing
- Non-recurring engineering costs
    - Board fabrication and population
    - Device thinning/delidding
    - Cables, connectors, parts, miscellaneous
    - Test equipment purchase/rental
- Facility Costs
  - Note that estimating the amount of beam time required is non-trivial – modes of operation, ions, temperature, power, etc. all factor into the test matrix and need to be prioritized.
- Travel
- Shipping



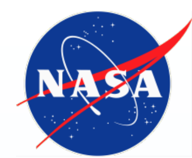
Device Constraints

- DUTs can range from very simple transistors to the most complex SOC.
  - This range implies test set implementations can vary just as widely.
- Starting points are always two-fold :
  - The datasheet for the DUT and
  - The application/suite of applications that will operate in space or are of research interest.
- We note that implementing a test set hinges greatly on the DUT type and requirements. However, a detailed discussion of this is out of scope for this talk.



Note on DUT Constraints

- While the usual "test as you fly" concept is applicable to simple devices (for example, an operational amplifier application), the more complex the device (for example, an FPGA), the more challenging it becomes to design an appropriate test (and build a reliable tester).
  - This is due to the accelerated nature of the SEE test versus space particle rates. Actual flight designs might not be appropriate for gathering sufficient information because their state-space and functional block coverage may not be statistically significant during short beam test run times.
- It is important to note that due to the huge number of application options modern complex devices are capable of, most SEU testing is geared to provide application-specific information.
  - Interpreting this data is challenging, at best, for other applications.

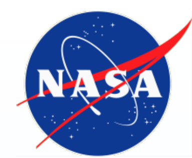


DUT Parameter Space

- DUT parameter space may include multiple items found on datasheets:
  - Electrical performance,
    - Frequency, timing, load, drive, fanout, IO, …
  - Application capability/operating modes,
    - Processing, configuration, utilization…
  - Power,
  - Environmental characteristics, and so on.
- Mission-specific testing will limit the parameter space as part of the requirements.
  - Research tests must consider the overall application space of the DUT and determine priorities for configuration of tests.
- We note that device sample size is also considered and may be limited due to resource or other constraints.
  - Good statistical methods are still recommended.
  - Lot qualification issues should be considered.
- Key features, device markings, etc. should be included.

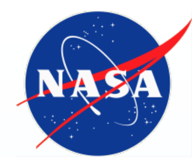
Predicting what you might observe - DUT SEE Categories

- An analysis of the types of SEE that may occur during irradiation is required.
  - This may be called a error/failure mode analysis.
  - Predicted type, and even frequency of SEEs, will drive the data capture requirements discussed later as will error propagation/visibility.
- An analysis should include:
  - Upset (single, multiple, transient, functional interrupts, etc.) and destructive issues, as well as,
  - Mission-specific objectives (e.g., application requirements or destructive test only).
- Note: Reviewing existing data on similar device types and technologies may help this process.



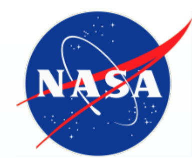
Test Set Requirements

- Test set requirements are a set of derived requirements from the mission/DUT/facility requirements.
  - Example: requirement for a test in vacuum may be different than one in air.
- Knowing how a DUT performs is one thing, but defining requirements for a test system is clearly separate.
  - Test set requirements should encompass actual application range or have sufficient flexibility such that modifications can be made on site easily.
- Mission Requirements generally have ranges of operation.
  - The test set should accommodate this range in areas such as:
    - Min, max, and typical (speed, temperature, voltage),
    - Variety of inputs,
    - Static and dynamic test capabilities, and,
    - Output loading.
- **We note that a test plan should provide full details, schematics, figures, photos, etc. of test method/set.**



Data Requirements

- Data requirements may be broken into two categories:
  - Data capture, and,
  - Data analysis.
- Data capture, in this context, is not how you capture the data, but the requirements/items that should be considered for capture.
- Data analysis is the other end of the picture: everything from the system-wide flow of the data, what format it is being captured in, and what are the requirements for analyzing this data (real-time and post-testing, as well as planning how this should be implemented.
- We suggest treating radiation data much like a spacecraft treats science data: a telemetry and command system.
  - Utilize as many reliable design practices as possible to have confidence in the results.

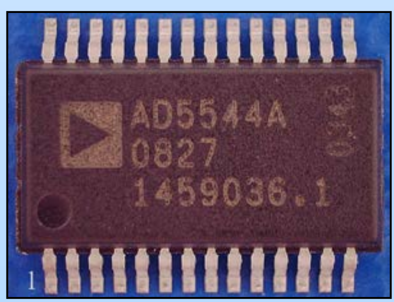


Processing the Data

- Every plan should include a discussion of how the data will be processed whether it’s:
  - FWHM for transients,
  - Physical mapping of errors and multiple bit events, or
  - Any of the myriad of data events in between.
- Requirements need to be divided into three categories:
  - Real-time (during the beam run),
  - Off-line (between beam runs), and,
  - Post-processing (after completion of beam runs).

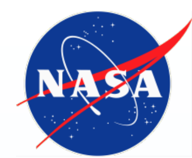
Facility Considerations

- **Each test facility has unique requirements including:**
  - The beam characteristics (energies, profile, etc.) – this drives issues such as DUT deprocessing,
  - DUT board mounting (vacuum/air, mounting plate, thermal interface, etc.),
  - Cabling (distance, feedthrus, etc.), and so on.
- **Test plans need to take these into consideration to ensure reliable testing.**



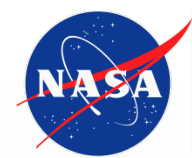
Acid etch/de-pot plastic encapsulated microcircuits (PEMs)

Avoid the dreaded CABLE CADAVER



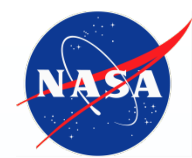
Configuration Management

- **The rule here is simple: know and document what you have, what you are using, and how you are using it. This ranges from cabling all the way to coding!**
  - **CM defines which version you have and making sure you bring the tools to modify if needed.**
    - **Examples: which VHDL code is the final one for either the test set or DUT (if applicable)?**
    - **Each team member is responsible for CM.**
- **Data backup is related.**
  - **Make sure you have a plan for storage of multiple copies of the data, who is responsible, and what happens for post-processing.**



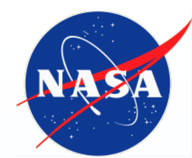
Logistics

- While non-technical, logistics related to test planning and writing a test plan are no less important.
- Areas for consideration in no particular order:
  - Test team member contact info (cell phones, hotels, flights, etc.),
  - Facility contact information including maps for “newbies,”
  - Contact information for key people at home site,
  - Equipment list including spares,
    - Don’t forget datasheets!
  - Shipping/transport of equipment (cost, tracking, etc.), and,
  - Roles and responsibilities of the team.



Contingency

- Contingency is required for several reasons:
  - Test set does not work;
  - Test set does not work as well as expected;
  - Error signatures are different than anticipated; or,
  - Facility may have an “issue” such as the beam going down.
- A good plan will include:
  - Prioritization of tests planned (which devices, which tests);
  - Limits on debug time to make a decision to test, move to a later test timeslot, etc.; and,
    - Example: if after 1.5 hours no significant progress is made, go to backup device.
  - Backup devices (in case test ends early or other device/test doesn’t work properly).



SEE Test Plan Outline - Summary

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- Documentation
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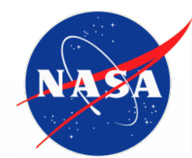
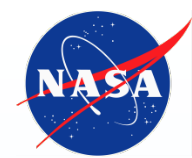
  - Photos of device and test set
- Equipment list
  - Packing and shipping information (detailed)
- Test methodology and data capture
  - Including data storage structure
- Configuration management
  - Data backup and distribution plan
- Personnel and logistics
- Data analysis plan
- Contingency plan



Summary

- This presentation was designed to provide the user the basic thought processes required to develop a successful test plan focusing on:
  - Technical issues,
  - Logistics issues, and,
  - Programmatic issues.
- We note that every DUT is different and no two test plans look alike.



Acknowledgements

- The authors would like to acknowledge our sponsors and collaborative agencies:
  - NASA Electronic Parts and Packaging (NEPP) Program, and,
  - The Defense Threat Reduction Agency (DTRA).
- We would also like to thank:
  - Martha O'Bryan for her presentation support, and,
  - Lew Cohn for his valuable discussions.