JEDEC STANDARD

Test Method for Beam Accelerated Soft Error Rate

JESD89-3B

Addendum No. 3 to JESD89

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1 Scope

This test method is offered as a standardized procedure to determine the terrestrial cosmic ray (i.e., high energy and thermal neutron) Soft Error Rate (SER) sensitivity of solid state volatile memory arrays and bistable logic elements (e.g., flip-flops) by measuring the error rate while the device is irradiated in a neutron or proton beam of known flux.

JESD89 describes considerations for executing such an estimate from data collected with this method. Refer to JESD89 for other background on the motivation for requirements in this test method and guidance for those elements left to the discretion of the tester. The results of this accelerated test can be used to estimate the terrestrial cosmic ray induced SER for a given terrestrial cosmic ray radiation environment.

NOTE 1 This test cannot be used to project alpha-particle-induced SER.

NOTE 2 Special considerations apply to devices that are more than memory arrays and/or bistable logic elements. These can preclude the application of this test procedure. Refer to JESD89 for further discussion on some examples.

2 Applicable documents

JESD89	Measurement and Reporting of Alpha Particles and Terrestrial Cosmic Ray-Induced Soft Errors in Semiconductor Devices
JESD89-1	Test Method for Real-Time Soft Error Rate
JESD89-2	Test Method for Alpha Source Accelerated Soft Error Rate

3 Apparatus

The performance of this test requires equipment that is capable of providing the particular test conditions to which the test samples will be subjected.

3.1 Vehicle design and operation

The biasing and operating schemes shall consider the limitations of the devices and shall not overstress the devices or contribute to thermal runaway.

3.2 Device mounting

Equipment design, if required, shall provide for mounting of devices to minimize adverse effects while parts are under test (e.g., improper heat dissipation).

3 Apparatus (cont'd)

3.3 Power supplies and signal sources

Instruments (e.g., oscilloscopes) used to set up and monitor power supplies and signal sources shall be calibrated and have long-term stability. Electrical noise shielding shall be in place to allow for accurate test results.

3.4 Scattered/stray radiation

- Special attention should be taken with respect to the effects of scattered radiation from the beam on the test setup. Technical personnel operating the facility should be consulted in terms of the relative flux of the forward and backward scattering distribution of the beam. They should also be consulted on effectiveness of shielding materials for the main beam and scattered beam attenuation.

- Spectral purity (e.g., energy and species) is also important. Scattering of the primary beam with material upstream from the DUT can generate additional radiation. Technical personnel operating the facility should be able to provide an estimate of the relative intensity of this stray radiation and effective means to shield it from the experiment. For example, thermal neutrons will be present in any high energy neutron beam, but use of material rich in B-10 can act as an effective attenuator (refer to JESD89 for details). This enables distinction of device effects due to high energy neutrons from those due to thermal neutrons.

- The results of the testing should be due to radiation effects on the DUT and not from interaction of radiation with other components in the test. In particular, power supplies can be vulnerable to radiation-induced avalanche breakdown. Sensitive electronic circuits in the tester and any device on the DUT board (e.g., buffers or registers) can also be affected. Any of these components should be moved as far from the primary and scattered beam as possible or appropriate shielding should be used.

- Assure that the tester and power supply are not affected by scattered radiation from the beam before conducting tests in a new facility or before conducting tests with a new tester setup (including modified shielding of the tester). To assure this, position and shield the tester exactly as during actual tests except for the DUT that shall be positioned outside the beam or shall be shielded from the beam. With the beam on and the DUT shielded or otherwise not exposed to the beam, test the DUT. Tester setup verification is successful if no failures are observed. Unless otherwise specified, this tester setup verification test shall last as long as a typical test.

- Care shall be taken to prevent upsets from stray signals or noise in the cables to the DUT. A tester readiness check shall be performed as part of the test sequence to assure electrical noise immunity, see section 4.3.1.

4 Terms and definitions

absolute maximum rated temperature: The maximum junction or ambient temperature of an operating device as listed in its data sheet and beyond which damage (latent or otherwise) may occur. It is frequently specified by device manufacturers for a specific device and/or technology.

NOTE Manufacturers may also specify maximum case temperatures for specific packages.

absolute maximum rated voltage: The maximum voltage that may be applied to a device and beyond which damage (latent or otherwise) may occur. It is frequently specified by device manufacturers for a specific device and/or technology.

critical charge (Q_c): The minimum amount of collected charge that will cause a device node to change state and result in a single event upset (SEU).

DUT: Device under test.

ECC: Error correction code, sometimes called error detection and correction (EDAC).

failure cross section: The numbers of failures detected per fluence .

fluence (of particle radiation incident on a surface): The total amount of particles incident on a surface in a given period of time, divided by the area of the surface and represented by the upper-case symbol Φ in this standard.

NOTE This fluence is usually expressed in particles per unit area (e.g., n/cm^2). Fluence is the product of flux multiplied by exposure time.

flux: The time rate of flow of particles incident on a surface, divided by the area of that surface, and represented by the symbol $\dot{\Phi}$ in this standard. It is the time rate of change of the fluence Φ: $\dot{\Phi} = d\Phi/dt$.

NOTE 1 Flux is usually expressed in particles per unit area, per unit time (e.g., n/cm^{2}h).

NOTE 2 The term “flux” is used in this standard whereas other standards might use the term “flux density” for the same meaning.

golden part: A sample used to monitor the consistency of the beam and tester setup.

maximum operating voltage: The maximum supply voltage at which a device is specified to operate in compliance with the applicable device specification or data sheet.

minimum operating voltage: The minimum supply voltage at which a device is specified to operate in compliance with the applicable device specification or data sheet.

multiple-bit upset (MBU): A single event that induces upset of multiple-cells where two or more of the upsets occur in the same logical word (or frame/column/sector, etc. for FPGAs).

NOTE An MBU is a logical manifestation of a single event.

4 Terms and definitions (cont'd)

multiple-cell upset (MCU): A single event that induces several cells (e.g. memory cells or flip-flops) in an IC to flip their state at one time.

NOTE 1 The induced errors are usually, but not always, physically adjacent. This does not imply logical adjacency, since this will depend on how cells are placed and routed (interleaved).

power cycle soft error (PCSE): a single event effect that is not corrected by repeated reading or writing but can be corrected by removal and reapplication of power.

single-event burnout (SEB): An event in which a single energetic-particle strike induces a localized high-current state in a device that results in catastrophic failure.

single-event effect (SEE): An event initiated by a particle strike that causes a transient voltage or current pulse. Various types of SEE are shown in Figure 1 of JESD89.

single-event functional interrupt (SEFI): A single event effect (SEE) that causes the component to reset, lock-up, or otherwise malfunction in a detectable way, but does not result in permanent damage (i.e., hard error).

NOTE A SEFI is often associated with an SBU/MBU in a control bit or register , whereas an SEL is caused by the turn-on of a parasitic thyristor. Many SEFI events can be cleared with a component reset operation (see RSE). In cases where resetting some configuration registers requires a complete power cycle of the device, it can be difficult to distinguish between a SEFI and an SEL. A SEFI event does not nesessarily result in an extended increase in operational current like a high current SEL.

single-event gate rupture (SEGR): An event in which a single energetic-particle strike results in a breakdown and subsequent conducting path through the gate oxide of a MOSFET.

NOTE An SEGR is manifested by an increase in gate leakage current and can result in either the degradation or the complete failure of the device.

single-event hard error (SEHE): A hard error caused by a single event radiation strike.

single-event latch-up (SEL): An abnormal high-current state in a device caused by the passage of a single energetic particle inducing a parasitic thyristor to turn on and remain in a fixed state regardless of inputs, until the device is power cycled.

NOTE 1 Some SEL events result in a measureable current increase (e.g. latch-up of an IO circuit). Some SEL events may result in a difficult to detect increase in current (micro-SEL) compared to the quiescent current of the entire component (e.g.latch-up of memory cells within a common well).

NOTE 2 A high current SEL may cause permanent damage to the component and result in a hard error. Micro-SEL events are typically non-destructive due to the low current draw and can be cleared by power cycling.

single-event transient (SET): A time dependent radiation induced spurious current or voltage signal on a circuit node. A digital SET (DSET) occurs when an SET in a combinational logic gate (along data or control paths) propagates and is latched to create an error (SEU) in the output of a sequential element. An analog SET (ASET) is a spurious signal in an analog circuit (e.g. a spurious signal on an IO pin, etc.) that causes an erroneous output.

4 Terms and definitions (cont'd)

single-event upset (SEU): An error in a circuit that is not permanent (i.e., not a hard error) caused by a state change of a latch, flop, memory cell or other bistable element from a single energetic particle strike. The energetic strike can occur directly on the circuit element or propagate to that circuit (see SET).

NOTE In many documents and publications, SEU is used to include other soft errors, such as SEFI and SEL.

soft error: An erroneous output signal from a circuit that can be corrected by performing one or more normal functions of the device (e.g., retrying operation, rewriting data, power cycling, etc.) In many documents and publications, soft error is synonymous with SEU.

NOTE 1 The term refers to an error caused by radiation or electromagnetic noise (e.g. electromagnetic pulse from a nuclear event) and not to an error associated with a physical defect introduced during the manufacturing process. For the purposes of this standard, soft errors are considered to be single particle radiation induced events and not due to other sources, such as signal integrity or noise.

NOTE 2 The terms soft error and soft error rate (SER) have been adopted by the commercial IC industry while other terms, such as SEU, SEFI, etc.. are typically used by the avionics, space, automotive, functional safety and military electronics communities.

NOTE 3 The term "soft error" was first introduced (for DRAMs and ICs) by May and Woods of Intel in their April 1978 paper at the IRPS and the term "single event upset" was introduced by Guenzer, Wolicki and Allas of NRL in their 1979 NSREC paper (SEU of DRAMs by neutrons and protons).

5 Procedure

5.1 Radiation source

In order to do accelerated terrestrial SER measurements, a radiation source(s) is required that matches the energy spectrum of terrestrial cosmic rays. This can be accomplished by a broad-spectrum beam or by using multiple mono-energetic beams. For more information on the terrestrial energy spectrum, see JESD89.

5.1.1 Flux

Beam calibration requirements:

- A calibration for beam energy and flux shall be run prior to the first test and at the end of the last test. If the beam flux varies by <10%, interpolation of beam flux during the test runs is allowed. If it is anticipated that the beam flux will vary by 10% or more, intermediate calibration data shall be collected to characterize the beam variation over the course of the test.
- In situ (real-time) measurement of beam flux by a secondary measurement technique is preferred in situations where beam stability is a problem.
- The flux detector shall be calibrated according to procedures at the beam facility
- Uniformity across the beam area is a consideration. Consult the beam facility operator on characterization of the beam uniformity.

SER Linearity: Care shall be taken in interpreting the acceleration factor between the beam testing and the terrestrial cosmic ray flux. To establish linearity, a proportional reduction in SER of a DUT must be observed when the beam flux reduced. If not, action shall be taken to achieve linear SER behavior (e.g., reduce the beam flux, reduce the read cycle time for dynamic testing).

NOTE 1 Care should be taken in the method for reducing beam flux. If a moderator is used (e.g. metal foils, polyethelene, etc.), the shift in energy spectrum should be considered.

NOTE 2 Non-linearity with beam flux can have a variety of causes. Examples include slow device response time (as when multiple particle strikes happen faster than embedded ECC can reconcile them individually) or slow test equipment response time during a dynamic test (as when multiple particle strikes happen on a memory array before the tester has detected and corrected the soft error from the first particle strike).

PCSE incidents can show non-linear sensitivity to beam flux. This may specially motivate reducing the beam flux to avoid PCSEs caused by multiple neutrons or multiple protons that are not representative of single event effects in a terrestrial environment.

5.1.2 Fluence

The fluence to be used shall be specified by qualification requirements or other procurement documents relating to the SER requirements of the device. If beam flux is not constant during testing, special provisions shall be made for secondary in situ measurement (e.g., a detector monitoring flux real time behind the DUT, a detector measuring scattered flux, etc). The method used for translating time variation in flux to fluence shall be clearly stated along with the assumptions made in the final report.

5.1.3 Spectral purity

High energy radiation environments should be expected to contain a spectrum of radiation. The facilities operator shall provide characterization of extraneous radiation. For example, thermal neutrons can occur in high energy beams. See 3.4 for additional considerations.

5.2 Test conditions

5.2.1 Operating voltage, temperature, and frequency

Unless otherwise specified, the operating voltage and temperature shall be the nominal operating conditions specified for the device. In order to characterize cosmic ray sensitivity as a function of Qcrit, lower and higher voltages and temperatures are also permitted. When possible, the preferred frequency for data collection is the maximum use frequency. The test voltage, temperature, and frequency shall not extend beyond the absolute minimum and maximum ratings for the device and shall be agreed upon by the device manufacturer.

5.2.2 Biasing configurations

Device outputs may be unloaded or loaded to achieve the specified output voltage level. If a device has a thermal shutdown feature, it shall not be biased in a manner that could cause the device to go into thermal shutdown.

5.2.2.1 Beam accelerated SER test

Unless otherwise stated, the beam accelerated SER test shall be configured to provide write/read function to the entire available memory array or sensitive bistable circuit area of the device samples with insitu pass/fail recording while undergoing irradiation. Unless otherwise specified, the patterns or pattern suite shall consist of an equal mix of physical 1's and 0's for memory elements. Any asymmetry in radiation-induced bit flipping shall be noted in reporting the data. For bistable logic circuits, data shall be collected on each circuit element. For example, data collection is required to quantify the master and slave elements of a flip-flop circuit separately. Furthermore, it is recommended that the patterns or pattern suite approximate typical use.

For characterization purposes, test conditions can be modified. These conditions include supply voltages, clock frequencies, input signals, etc. that may be operated outside their specified values. When operating outside the application range of the part, predictable and nondestructive behavior of the devices under test shall be assured.

5.3 Test sequence

A minimal test sequence shall include:

1) Test readiness check for ‘golden’ part (see 5.3.1)
2) Beam and setup check for ‘golden’ part
3) Collect data for ‘golden’ part
   a. Tests to verify appropriate flux

   NOTE This is particularly important in order to compare results from different devices tested on different beam sources. The ‘golden’ part can be used to correlate the SER data from one facility to another.
4) Test readiness check for DUT
5) Collect data on DUT
   a. Tests to verify appropriate flux
6) Final test for DUT (see section 5.3.2)
7) Repeat steps 4 though 6 for additional parts
8) Where the verification of beam consistency is accomplished by collecting data on a part under test, repeat tests on a dedicated ‘golden’ part (as in Step 3) or on the first sample tested during the data collection session (as in the first execution of Step 5).

5.3.1 Test readiness

Prior to running the SER test, a tester readiness check shall be performed without the beam irradiating the sample (i.e., either by turning the source off or by shielding the sample). This check shall be performed with the hardware in the same manner as it will be used for the test. The tester readiness check shall verify all patterns and voltages to be used during accelerated beam testing on the part. If the test voltage will exceed the maximum operating voltage or will be below the minimum operating voltage, the test pattern shall be written and read at nominal voltage, and the voltage shall be changed to the test voltage in the same way as during the actual test. The check is completed successfully if no errors are detected during a tester check.

This check shall be performed before any test in which the test setup or DUT was changed.

5.3.2 Final test for each part

For each part tested, the final test shall repeat the initial test in order to verify the consistency of the results. The presence of new hard failures beyond any expected hard failure rate or a change in the measured failure rate beyond statistical and run-to-run variations could indicate total dose effects.

5.3.3 ‘Golden’ part

A ‘reference’ part can be used to confirm the beam uniformity between differing test dates. For each test date, the reference part shall be tested under the same test conditions as previous test date.

NOTE As described in JESD89, a candidate part should be selected for its tendency for a high rate of soft errors and a high resistance to total dose effects.

5.4 Sample description

Intervening materials can attenuate the beam between the source and the silicon to be tested. Exposing the bare die during testing is not necessary. When the total thickness of the intervening materials is sufficient to alter any beam property (flux or energy) by 10% or more or the materials are not relatively uniform in thickness, then the respective materials and thicknesses shall be explicitly included in any data report along with a description of the beam property alteration. Intervening materials can include:

- component packaging
- heat-sinks or other thermal enhancements
- other devices under test and the mounting substrate or associated fixturing

If heat-sinks are required to operate the DUT at rated frequencies or timings, forced or cold air cooling (e.g., thermo stream) may be necessary and heat-sink thickness shall be kept to a minimum.

5.4.1 Special Considerations for Neutron Beams

Material between the active surface of the device and the incident beam should be minimized in order to reduce the following effects:

1) Neutron attenuation and secondary particle generation (both neutrons and ions) due to spallation (i.e., nuclear breakup) from the beam neutrons hitting the nuclei of the target material,
2) Reduction in flux due to scattering causing the beam to spread out, especially in the case of stacked devices,
3) Neutron beam energy change (i.e., energy spectrum shift) from processes 1) and 2).

If a heatsink is required, it should be as thin as possible. For thick heatsinks and finned heatsinks, the device should be irradiated from the backside if this orientation presents less intervening material. If multiple devices are stacked, spectrum shift, reduction in flux and secondary particle generation become more significant. For most ICs, the material in the beam changes the flux and energy spectrum of the neutron beam by less than 1%, but very large high-power-dissipation chips irradiated through thick heat sinks can cause flux changes over 10%. See JESD89B A.6 “Effects of shielding by buildings and other material”.

NOTE For examples of material effects on neutron beam properties, the effects of a relatively thin and extremely thick IC placed in the neutron beam of the Irradiation of Chips and Electronics (ICE) House of the Los Alamos Neutron Science Center were calculated using the radiation transport code MCNP6 (https://mcnp.lanl.gov/).

EXAMPLE 1 – Frontside Irradiation of Simple Package and DUT Board
At the active surface of an IC irradiated through 1 mm of aluminum heat spreader and a 1 mm epoxy package, with 0.5 mm epoxy substrate and 3 mm epoxy-fiberglass circuit board downstream, the neutron flux above 10 MeV increases by 0.1%, secondary protons above 50 MeV add another 0.1% to the high-energy nucleon flux, and the mean beam energy decreases by 0.2% — all negligible.

EXAMPLE 2 – Backside Irradiation of Complex Package and DUT Board
For the case of an IC with an 81 mm thick aluminum heat-sink with fins, 6.9 mm of copper, and 1.15 mm of silicon above the active surface and a 3.5 mm package and socket, 3 mm DUT circuit board, and 2.2 mm steel back plate below the active surface, irradiation through the DUT board leads to the neutron flux above 10 MeV increasing by 1.6%, secondary protons adding 0.4% to the high-energy nucleon flux, and the mean beam energy decreasing by 2.4%.

5.4.1 Special Considerations for Neutron Beams (cont'd)

EXAMPLE 3 – Frontside Irradiation of Complex Package and DUT Board
If irradiation for the device in Example 2 is through the tall heat sink, the neutron flux above 10 MeV decreases by 13.6%, the secondary proton flux above 50 MeV is 1% of the initial neutron flux, and the mean energy of the beam increases by 1.8%.

5.4.2 Special Considerations for Proton Beams

If a proton beam is used, the primary effect of interaction between the beam and the intervening package and heat-sink materials is reduction of the beam energy. The change in proton energy (ΔE_i) going through a material of thickness t_i between the incident beam and that impinging on the active circuit is given by the integral

$$\Delta E_i = \int_{x=0}^{x=t_i} (dE_i/dx)\ dx \qquad (3)$$

where (dEi/dx) is the proton energy loss per unit length. This energy loss applies through a variety of materials including heat-sink materials like copper and aluminum and component packaging materials like plastic and ceramic. Values can be found in The Stopping Range of Ions in Matter by J.F. Ziegler, J.P. Biersack and U. Littmark, Pergamon Press, New York, 1985. For convenience, Appendix A gives a tabulation of energy loss of protons in common packaging and heat-sink materials. For more detailed data and different materials, other references may be used. For example, SRIM software can be downloaded from www.srim.org. (The projected range v. proton energy is also shown for informational purposes. This is approximately the distance a proton with a given energy will travel before it has given up its entire energy.)

Like neutrons, high-energy protons also undergo nuclear scattering and cause secondary particle generation by spallation of the nuclei of the target material.

As with neutrons, the material between the active surface of the device and the incident proton beam should be minimized~~ as much as possible~~. A total proton energy loss of <10% is recommended to avoid secondary ion effects.

CAUTION — Under no circumstances should the intervening material between the incident beam and the circuit approach the projected ranges shown in Appendix A since packaging effects will then dominate the SER behavior of the DUT.

NOTE For examples of material effects on proton beam properties, the effects of a relatively thin and extremely thick IC placed in a 200 MeV proton beam were calculated using the radiation transport code MCNP6 (https://mcnp.lanl.gov/). The chips are the same ones described in the examples above in the note for neutron beams. At the active surface of the thin chip (Example 1), the proton flux above 50 MeV increases by 0.04%, secondary neutrons above 10 MeV add another 0.4% to the high-energy nucleon flux, and the mean beam energy decreases by 0.1% — all negligible. At the active surface of the thick chip irradiated through the circuit board (Example 2), the proton flux above 50 MeV decreased by 0.7%, secondary neutrons add 3.6% to the high-energy nucleon flux, and the mean proton beam energy decreases by 1.5%. Irradiated through the tall heat sink (Example 3), the proton flux above 50 MeV decreases by 13.4%, the secondary neutron flux above 10 MeV is 6% of the initial proton flux, and the mean energy of the proton beam decreases by 46%.

The amount of energy loss shall be calculated and included in the final report. Annex A must also be used as a correction factor in estimating the total SER failure cross-section as detailed in JESD89.

5.4 Sample description (cont'd)

5.4.3 Special Considerations for Thermal Neutron Testing

When testing with a thermal neutron beam, identify any materials which contain Boron-10. (The B-10 isotope attenuates a thermal neutron beam.) If the Boron-10 is in close proximitity to the active area, thermal neutron capture can lead to soft errors from the energetic ions generated (see JESD89B, Sec. 7).

5.5 Handling

All testing shall follow appropriate procedures for safe handling of radioactive materials and ESD control. Devices irradiated by high energy sources can become radioactive. It may be necessary to leave exposed test samples and test equipment at the test facility until their level of radioactivity has reduced; shipping radioactive test samples and test equipment may require special licenses. Appropriate quarantine procedures established by the beam facility should be followed.

6 Failure criteria

Any result that does not match expectation is a possible soft error and shall be recorded. Care shall be taken to minimize electrically noisy test environments and, thereby, errors related to the equipment and not the device. Consideration shall be given to discriminating among the error types which can be encountered.

To differentiate among soft errors, power-cycle soft errors (PCSE) and single-event hard errors (SEHE), data shall be rewritten into the device and re-read. If the error is corrected by re-writing (or resetting the register in the case of a device register upset), it shall be considered a soft error. If the error repeats after re-writing (or resetting the register in the case of a device register upset), it is not likely to be a soft error, for example, a non-destructive SEL. When an error persists after re-writing (or resetting the register in the case of a device register upset), the chip shall undergo a power-cycle, where the power is removed then restored. After the power-cycle, both data states shall be written into and re-read from the faulting bits. Any faulting bits that can be written into both data states and re-read from both data states without error after the power-cycle shall be recorded as power-cycle soft errors. Faults which persist after writing into or re-reading either data state after the power-cycle shall be recorded as hard errors. PCSE and SHE shall be counted separately from memory bit soft errors or register upsets.

NOTE Upset of a device register may be cleared by resetting the register while maintaining power as well as by a power-cycle. Upset due to a parasitic thyristor can only be cleared by removal of power to the thyristor.

A single proton or neutron can directly upset multiple memory cells. Care is required to identify multiple-cell errors. In static tests, if the total number of errors is sufficiently small so that the probability of physically proximate errors occurring from independent events remains negligible, then physically proximate errors can reasonably be assumed to be a multiple-cell upset from a single proton or neutron. In dynamic runs, if 1) the tester is able to record all detected errors and 2) the time to read to whole array is small enough that the probability of physically proximate errors occurring from independent events remains negligible, then physically proximate errors can reasonably be assumed to be a multiple-cell upset from a single proton or neutron. The multiple-cell error rate may be included in the final report.

6 Failure criteria (cont'd)

Any soft error that affects multiple cells in a single read period through the memory array --and that cannot be otherwise demonstrated to be a set of independent cell errors -- shall be reported as a multiple-cells error and classified and counted according to its failure signature. The independence of cell errors can be demonstrated by distinct separation in the time of occurrence, established separation of failing physical addresses, and/or independence of the local array controls and supports for the affected cells.

NOTE 1 An assessment of fault independence based on a distinction of tester timestamps shall consider the delay time between the event and read record. (For example, two errors caused by the same event can have different tester timestamps depending on when they are read within the read cycle of the entire chip and when the event happens within that read cycle.)

NOTE 2 Upset of logic circuits that control reads and writes to a memory array could lead to the appearance of many cell errors. This case should be considered if there are multiple cell errors from a single event that appear to have no physical relationship in the array.

Where possible, it is desirable to identify the subset of PCSE that are SEL (as by measurement of anomalous current). Likewise where possible, it is desirable to identify the subset of soft errors that are SEFI. For memory arrays, SEFI may be distinguishable by the extent of related array addresses that are affected (as in an entire array or array subset dependent on operation of a common latch).

7 Report

The following items shall be contained in the final report for any beam source accelerated SER test:

a) Description of beam source, including

   1) Facility, location, facility contact information, description of the source generation, particle type (neutron, proton)

   2) Beam energy (monoenergetic) or energy spectrum description

   3) Filters used, if any (e.g., cadmium strip or borated shield for thermal neutrons)

   4) Variation in beam flux or fluence during testing, including description of the monitor technique or method of estimation

   5) Description of beam with respect to each DUT, including
      a) Beam flux at DUT
      b) Beam area and uniformity of beam across DUT
      c) DUT orientation to incident beam
      d) Material in front of the DUT and immediately behind the DUT (backscattering effects). This includes any heatsinks
      e) Spacing between boards if multiple boards are tested
      f) Presence of B-10 in the DUT and packaging material, if known

b) Sample size (number of devices) tested and amount of circuits (array sizes, scan chain size, etc) tested on each device

7 Report (cont'd)

c) Vehicle description, including

1) Circuit type and sub-element (e.g., SRAM, DRAM, flip-flop master, flip-flop slave)
2) Package description (e.g., connection to chip, materials, and geometries), including any modifications made for SER testing (e.g., non-standard heatsink)
3) Supplier part number (and die revision, if applicable)
4) Operational description of the circuit
5) ECC description (type and coverage) or "tested per data sheet, ECC unknown"

d) Test description, including

1) Voltage (external supply, use of internal regulated, back bias if applicable)

   NOTE Reporting an internal regulate voltage level is optional, but encouraged where the portability of the data to other devices is of interest
2) Test pattern(s), including logical data pattern and, if known, the physical data pattern.
3) Fluence and test duration
4) Core cycle time or frequency with special notation of cycle times different than product data sheet (for dynamic test) or designation as "static"
5) Refresh rate, where applicable
6) Temperature during test (at minimum, ambient temperature; if available, junction temperature as well. Report the means for determining the junction temperature)
7) Which source and energy, if multiple sources and energies are used
8) Tester (commercial model and/or physical description)
9) Problems or unusual behavior of the devices during test
10) Fail information
    a) Count of each error type (types of soft errors and description of hard errors, if any)

       NOTE Because test durations are often relatively short, hard error observations are typically exceptional. Where total dose effects drive those errors, they are test artifacts only and those observations should be specially identified as such.
    b) Identification of those soft errors that are multiple-cell errors
    c) Electrical signature of hard errors
    d) Failing logical address or addresses

       NOTE Interpretation of multi-cell errors is enhanced by an understanding of the physical relationship of failing addresses.
    e) Test conditions (voltage, ECC usage, data pattern, etc.) where multiple conditions are applied within the same test
    f) Failure rate in test condition. Ideally, the failure rate should be identified on both a per-bit (or other circuit element) basis as well as a per-event basis. At minimum, the basis for any given failure rate shall be clearly identified.

7 Report (cont'd)

11) Periodicity of test readouts

12) The measured SER; where available, it includes the single-bit and multi-bit components and a description of how the multi-bit component was determined.

e) Test results, by DUT location if DUTs are not uniform in their exposure to the beam (e.g., stacked DUTs, differing distances from the beam) , including the measured failure rate and failure cross section. Where observed, categorize by a) single-cell upset, b) multi-cell errors, c) latch up, d) address or command errors, e) upset of redundancy latches and provide a description of how these components were determined.

   1) Linearity - Show the failure rate is directly proportional to the flux.

   2) Multiple errors – Demonstrate multiple errors are from single energetic events

If available, it is recommended to document the following information:

a) Dimensions of active area tested on the device

b) Process technology features (e.g., lithographic node, number and type of metal levels, post-metal insulators like polyimide, deep N-well, silicon-on-insulator)

c) Plot of the beam energy spectrum

d) Extrapolated product SER. Refer to JESD89 for guidance on extrapolating test results to the terrestrial neutron rates for product use. All assumptions for transforming data shall be clearly explained, including but not limited to

   1) Package description (e.g., wire bond, flip chip, heatsink)

   2) Memory or logic device description (single-port or dual-port memory, flip-flop type, etc.)

   3) Derating factors, such as error correction circuits

   4) Estimation method for energy-dependence of failure cross section, if applicable (see JESD89 for calculation techniques).

   5) Correction factor for flux attenuation due to material between the beam source and the device silicon

   6) For thermal neutron testing, correction factor for flux attenuation if any material between beam source and device silicon contains B-10

   7) Process layer stack (metals and dielectics)

Annex A Proton energy loss

Table 1 — Proton energy loss in aluminum

Proton Energy	dE/dx (MeV/mm)	Projected Range
1 MeV	4.726E+01	14.38 um
2 MeV	2.993E+01	41.63 um
3 MeV	2.252E+01	80.38 um
4 MeV	1.829E+01	129.71 um
5 MeV	1.552E+01	188.98 um
6 MeV	1.354E+01	257.80 um
7 MeV	1.206E+01	335.85 um
8 MeV	1.089E+01	422.78 um
9 MeV	9.952E+00	518.46 um
10 MeV	9.177E+00	622.71 um
15 MeV	6.694E+00	1.27 mm
20 MeV	5.340E+00	2.11 mm
25 MeV	4.479E+00	3.13 mm
30 MeV	3.879E+00	4.33 mm
35 MeV	3.435E+00	5.69 mm
40 MeV	3.093E+00	7.23 mm
45 MeV	2.821E+00	8.91 mm
50 MeV	2.599E+00	10.75 mm
55 MeV	2.414E+00	12.74 mm
60 MeV	2.257E+00	14.88 mm
65 MeV	2.123E+00	17.16 mm
70 MeV	2.006E+00	19.57 mm
80 MeV	1.814E+00	24.80 mm
90 MeV	1.661E+00	30.55 mm
100 MeV	1.537E+00	36.79 mm
150 MeV	1.154E+00	74.77 mm
200 MeV	9.543E-01	122.62 mm
250 MeV	8.323E-01	178.77 mm
300 MeV	7.501E-01	242.04 mm
350 MeV	6.912E-01	311.42 mm
400 MeV	6.472E-01	386.09 mm
450 MeV	6.131E-01	465.32 mm
500 MeV	5.861E-01	548.58 mm
550 MeV	5.643E-01	635.37 mm
600 MeV	5.463E-01	725.26 mm
650 MeV	5.314E-01	817.90 mm
700 MeV	5.188E-01	912.96 mm
800 MeV	4.990E-01	1.11 m
900 MeV	4.844E-01	1.31 m
1.00 GeV	4.732E-01	1.52 m

Values from SRIM-2003.26; reference J. F. Ziegler, "SRIM 2003", Nucl. Inst. Methods, vol. 219-220, 1027-1036 (2004)

Annex A Proton energy loss (cont'd)

Table 2 — Proton energy loss in copper

Proton Energy	dE/dx (MeV/mm)	Projected Range
1 MeV	1.060E+02	6.72 um
2 MeV	7.113E+01	18.35 um
3 MeV	5.529E+01	34.23 um
4 MeV	4.581E+01	53.96 um
5 MeV	3.940E+01	77.29 um
6 MeV	3.474E+01	104.08 um
7 MeV	3.117E+01	134.20 um
8 MeV	2.835E+01	167.51 um
9 MeV	2.605E+01	203.96 um
10 MeV	2.413E+01	243.47 um
15 MeV	1.789E+01	484.97 um
20 MeV	1.442E+01	795.54 um
25 MeV	1.218E+01	1.17 mm
30 MeV	1.061E+01	1.61 mm
35 MeV	9.435E+00	2.11 mm
40 MeV	8.525E+00	2.66 mm
45 MeV	7.798E+00	3.27 mm
50 MeV	7.201E+00	3.93 mm
55 MeV	6.703E+00	4.65 mm
60 MeV	6.279E+00	5.41 mm
65 MeV	5.915E+00	6.23 mm
70 MeV	5.599E+00	7.09 mm
80 MeV	5.074E+00	8.95 mm
90 MeV	4.657E+00	11.00 mm
100 MeV	4.318E+00	13.21 mm
150 MeV	3.259E+00	26.64 mm
200 MeV	2.705E+00	43.49 mm
250 MeV	2.365E+00	63.21 mm
300 MeV	2.135E+00	85.39 mm
350 MeV	1.969E+00	109.69 mm
400 MeV	1.845E+00	135.82 mm
450 MeV	1.749E+00	163.52 mm
500 MeV	1.673E+00	192.62 mm
550 MeV	1.612E+00	222.94 mm
600 MeV	1.561E+00	254.34 mm
650 MeV	1.519E+00	286.69 mm
700 MeV	1.483E+00	319.87 mm
800 MeV	1.427E+00	388.37 mm
900 MeV	1.385E+00	459.25 mm
1.00 GeV	1.354E+00	532.04 mm

Values from SRIM-2003.26; reference J. F. Ziegler, "SRIM 2003", Nucl. Inst. Methods, vol. 219-220, 1027-1036 (2004)

Annex A Proton energy loss (cont'd)

Table 3 — Proton energy loss in molded epoxy $H_{19}C_{18}O_3$

Proton Energy	dE/dX (MeV/mm)	Projected Range
1 MeV	45.58	13.93um
2 MeV	29.25	41.79um
3 MeV	21.56	82.02 um
4 MeV	17.25	134.12 um
5 MeV	14.48	197.50 um
6 MeV	12.53	271.78 um
7 MeV	11.08	356.64 um
8 MeV	9.95	451.72 um
9 MeV	9.05	556.91 um
10 MeV	8.31	672.02 um
15 MeV	5.98	1.39 mm
20 MeV	4.73	2.34 mm
25 MeV	3.94	3.50 mm
30 MeV	3.40	4.87 mm
35 MeV	3.00	6.43 mm
40 MeV	2.69	8.20 mm
45 MeV	2.45	10.14 mm
50 MeV	2.25	12.27 mm
55 MeV	2.09	14.58 mm
60 MeV	1.95	17.06 mm
65 MeV	1.83	19.70 mm
70 MeV	1.73	22.52 mm
80 MeV	1.56	28.61 mm
90 MeV	1.42	35.33 mm
100 MeV	1.31	42.64 mm
150 MeV	0.98	87.29 mm
200 MeV	0.81	143.80 mm
250 MeV	0.70	210.33 mm
300 MeV	0.63	285.48 mm
350 MeV	0.58	368.05 mm
400 MeV	0.54	457.08 mm
450 MeV	0.51	551.68 mm
500 MeV	0.49	651.23 mm
550 MeV	0.47	755.14 mm
600 MeV	0.46	862.90 mm
650 MeV	0.44	974.06 mm
700 MeV	0.43	1.09 m
800 MeV	0.41	1.32 m
900 MeV	0.40	1.57 m
1 GeV	0.39	1.82 m

Values from SRIM-2003.26; reference J. F. Ziegler, "SRIM 2003", Nucl. Inst. Methods, vol. 219-220, 1027-1036 (2004)

Annex A Proton energy loss (cont'd)

Table 4 — Proton energy loss in ceramic Al_20_3

Proton Energy	dE/dX (MeV/mm)	Projected Range
1 MeV	7.48E+01	8.92 um
2 MeV	4.86E+01	25.8 um
3 MeV	3.64E+01	49.78 um
4 MeV	2.94E+01	80.45 um
5 MeV	2.49E+01	117.44 um
6 MeV	2.16E+01	160.52 um
7 MeV	1.92E+01	209.49 um
8 MeV	1.73E+01	264.13 um
9 MeV	1.58E+01	324.37 um
10 MeV	1.46E+01	390.1 um
15 MeV	1.06E+01	797.74 um
20 MeV	8.41E+00	1.33 mm
25 MeV	7.04E+00	1.98 mm
30 MeV	6.08E+00	2.75 mm
35 MeV	5.38E+00	3.62 mm
40 MeV	4.84E+00	4.6 mm
45 MeV	4.41E+00	5.68 mm
50 MeV	4.06E+00	6.86 mm
55 MeV	3.77E+00	8.13 mm
60 MeV	3.52E+00	9.5 mm
65 MeV	3.31E+00	10.96 mm
70 MeV	3.13E+00	12.51 mm
80 MeV	2.83E+00	15.87 mm
90 MeV	2.59E+00	19.56 mm
100 MeV	2.39E+00	23.57 mm
150 MeV	1.79E+00	48.02 mm
200 MeV	1.48E+00	78.85 mm
250 MeV	1.29E+00	115.06 mm
300 MeV	1.16E+00	155.88 mm
350 MeV	1.07E+00	200.66 mm
400 MeV	1.00E+00	248.87 mm
450 MeV	9.50E-01	300.02 mm
500 MeV	9.08E-01	353.78 mm
550 MeV	8.74E-01	409.82 mm
600 MeV	8.46E-01	467.88 mm
650 MeV	8.23E-01	527.7 mm
700 MeV	8.04E-01	589.09 mm
800 MeV	7.73E-01	715.81 mm
900 MeV	7.50E-01	846.96 mm
1 GeV	7.33E-01	981.62 mm

Values from SRIM-2003.26; reference J. F. Ziegler, "SRIM 2003", Nucl. Inst. Methods, vol. 219-220, 1027-1036 (2004)

Annex A Proton energy loss (cont'd)

Table 5 — Proton energy loss in SiO_2

Proton Energy	dE/dX (MeV/mm)	Projected Range
1 MeV	44.04	14.97 um
2 MeV	28.83	43.46 um
3 MeV	21.59	83.83 um
4 MeV	17.47	135.45 um
5 MeV	14.77	197.69 um
6 MeV	12.86	270.16 um
7 MeV	11.42	352.53 um
8 MeV	10.30	444.44 um
9 MeV	9.40	545.77 um
10 MeV	8.66	656.31 um
15 MeV	6.29	1.34 mm
20 MeV	5.00	2.24 mm
25 MeV	4.18	3.33 mm
30 MeV	3.62	4.62 mm
35 MeV	3.20	6.09 mm
40 MeV	2.88	7.73 mm
45 MeV	2.62	9.55 mm
50 MeV	2.41	11.53 mm
55 MeV	2.24	13.67 mm
60 MeV	2.09	15.98 mm
65 MeV	1.97	18.43 mm
70 MeV	1.86	21.04 mm
80 MeV	1.68	26.68 mm
90 MeV	1.54	32.89 mm
100 MeV	1.42	39.64 mm
150 MeV	1.07	80.75 mm
200 MeV	0.88	132.61 mm
250 MeV	0.77	193.52 mm
300 MeV	0.69	262.17 mm
350 MeV	0.64	337.49 mm
400 MeV	0.60	418.56 mm
450 MeV	0.56	504.6 mm
500 MeV	0.54	595.01 mm
550 MeV	0.52	689.27 mm
600 MeV	0.50	786.91 mm
650 MeV	0.49	887.52 mm
700 MeV	0.48	990.76 mm
800 MeV	0.46	1.2 m
900 MeV	0.45	1.42 m
1 GeV	0.44	1.65 m

Values from SRIM-2003.26; reference J. F. Ziegler, "SRIM 2003", Nucl. Inst. Methods, vol. 219-220, 1027-1036 (2004)

Annex A Proton energy loss (cont'd)

Table 6 — Proton energy loss in Si

Proton Energy	dE/dX (MeV/mm)	Projected Range
1 MeV	4.073E+01	16.33 um
2 MeV	2.609E+01	47.69 um
3 MeV	1.970E+01	92.05 um
4 MeV	1.603E+01	148.36 um
5 MeV	1.362E+01	215.93 um
6 MeV	1.189E+01	294.32 um
7 MeV	1.059E+01	383.14 um
8 MeV	9.576E+00	482.01 um
9 MeV	8.754E+00	590.78 um
10 MeV	8.075E+00	709.23 um
15 MeV	5.900E+00	1.44 mm
20 MeV	4.711E+00	2.39 mm
25 MeV	3.953E+00	3.55 mm
30 MeV	3.425E+00	4.91 mm
35 MeV	3.034E+00	6.46 mm
40 MeV	2.733E+00	8.19 mm
45 MeV	2.493E+00	10.10 mm
50 MeV	2.297E+00	12.18 mm
55 MeV	2.133E+00	14.43 mm
60 MeV	1.995E+00	16.85 mm
65 MeV	1.877E+00	19.42 mm
70 MeV	1.774E+00	22.16 mm
80 MeV	1.604E+00	28.07 mm
90 MeV	1.469E+00	34.56 mm
100 MeV	1.359E+00	41.62 mm
150 MeV	1.020E+00	84.55 mm
200 MeV	8.443E-01	138.63 mm
250 MeV	7.364E-01	202.08 mm
300 MeV	6.638E-01	273.57 mm
350 MeV	6.118E-01	351.95 mm
400 MeV	5.728E-01	436.30 mm
450 MeV	5.427E-01	525.80 mm
500 MeV	5.188E-01	619.84 mm
550 MeV	4.995E-01	717.86 mm
600 MeV	4.837E-01	819.40 mm
650 MeV	4.705E-01	924.02 mm
700 MeV	4.593E-01	1.03 m
800 MeV	4.419E-01	1.25 m
900 MeV	4.289E-01	1.48 m
1.00 GeV	4.191E-01	1.72 m

Values from SRIM-2003.26; reference J. F. Ziegler, "SRIM 2003", Nucl. Inst. Methods, vol. 219-220, 1027-1036 (2004)

Annex B (informative) Differences between JESD89-3B and JESD89-3A

This table briefly describes most of the changes made to entries that appear in this standard, JESD89-3B, compared to its predecessor, JESD89-3A (November 2007). If the change to a concept involves any words added or deleted (excluding deletion of accidentally repeated words), it is included. Some punctuation changes are not included.

Page **Description of change**

SECTION	DESCRIPTION OF CHANGE
1 Scope	Added high energy and thermal neutron explicitly to description of terrestrial cosmic rays.
4 Terms and definitions	Various definintions have been update to align with JESD89B
5.1 Radiation source	Note added that if beam moderator is used, impact on energy spectrum should be considered.
5.4 Sample description	Note removed on avoiding use of finned heatsinks since more details are added to Sec. 5.4.1.
5.4.1 Special Considerations for Neutron Beams	Formulas for neutron attenuation removed and replaced with examples derived from radiation transport code MCNP6.
5.4.2 Special Considerations for Proton Beams	Examples of proton interaction with packages added to complement neutron examples in Sec 5.4.1
5.4.3 Special Considerations for Thermal Neutron Testing	Added reference to JESD89B Sec. 7 if the Boron-10 is in close proximitity to the active area.
6 Failure criteria	Updated failure descriptions to comply with JESD89B definitions.
7 Report	Added additional description of material in front of and behind the DUT, spacing between boards and presence of B-10.
Annex A Proton energy loss	Corrected errors in 100 and 150MeV proton range in Si and removedd insignificant figures in tables.

Annex B.1 (informative) Differences between JESD89-3A and JESD89-3

This table briefly describes most of the changes made to entries that appear in this standard, JESD89-3A, compared to its predecessor, JESD89-3 (September 2005). If the change to a concept involves any words added or deleted (excluding deletion of accidentally repeated words), it is included. Some punctuation changes are not included.

Page **Description of change**

A change record was not provided at time of publication.

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