AN54908

Accelerated Neutron SER Testing and Calculation of Terrestrial Failure Rates

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This application note describes the accelerated neutron testing procedure and test conditions that are applied during device qualification for Cypress SRAM devices. It covers Synchronous SRAM, Asynchronous SRAM, More Battery Life™ MoBL® SRAM, and Nonvolatile SRAM (nvSRAM) but does not contain soft error rate (SER) data for any of the SRAMs. Individual datasheets for Synchronous SRAMs list the derived accelerated neutron failure rates. SER data for other product families is available by request through Cypress Customer Care.

1 Introduction

The earth's atmosphere receives various kinds of atomic, or nuclear, radiation coming from outer space. The term *soft fails* indicates spontaneous (and temporary) changes in digital information due to radiation effects. Among all kinds of radiation, high-energy cosmic-ray neutrons have been reported to cause the most damage in modern-day electronics. The origin of these cosmic rays striking the earth's atmosphere is either the sun (energies up to 1 GeV) or isotropic galactic particles (energies > 108 GeV). The flux of these particles depends on the altitude and the geographical location. These high-energy neutrons create a burst of energy in the semiconductor substrate and form the most dominant soft error source.

Table 1 tells where you can get soft error rate (SER) data for various families of SRAM devices.

Table 1. SER Data for Various SRAM Families

SRAM Product	Technology	Where to find SER or SEL data
Synchronous SRAM	90 nm, 65 nm	Datasheets
Synchronous SRAM	150 nm, 300 nm, 400 nm	Raise a Technical Support case
Asynchronous and Other SRAMs	All nodes	Raise a Technical Support case

2 SER Failure Mechanism

Figure 1 and Figure 2 illustrate the impact of soft errors in SRAMs.

Figure 1. Cross-Section of a Portion of Any CMOS SRAM

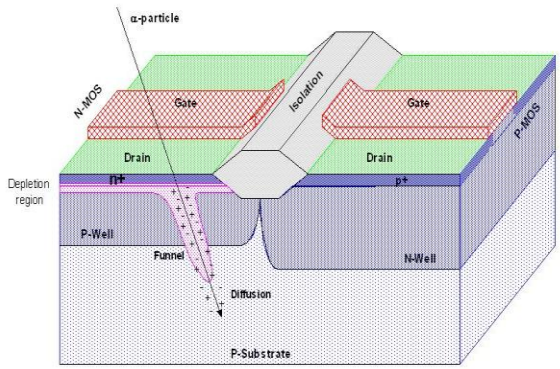
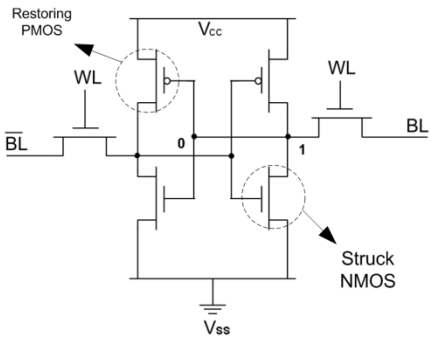


Figure 2. The Effect of a Particle Hit On a 6T SRAM Cell



As Figure 2 shows, an incident particle generates electron hole pairs directly (alpha particle) or indirectly (high-energy neutron, causing a burst of charge) in the SRAM. The electric field in the depletion region causes the charge to be collected by the junction, resulting in the current disturb of the struck MOS (NMOS). The restoring MOS (PMOS) tries to balance it, but its finite current drive and the channel conductance induce a voltage disturb in its drain. If this transient voltage pulse overcomes the threshold charge of the cell, the stored data flips.

3 Definitions

SER is defined as the probability that a device will fail. Usually it is expressed in failure-in-time (FIT) units, which are failures per 10^9 hours. A list of the major single event effect (SEE) phenomena and their definitions follows here:

- **Physical single-bit upset (PSBU):** This failure type involves a single particle causing only a single memory cell of the memory array to fail.
- **Physical multibit upset (PMBU):** This failure type involves a single particle causing more than one bit to fail in the physical memory array. By contrast, a multi cell upset (MCU) describes only the event itself and does not further specify how many bits are upset. This failure type involves more than one cell in the physical memory array changing its state. It can involve two to several hundreds of bits, depending on the particle.
- **Logical single-bit upset (LSBU):** This refers to the number of failing memory bits in the data word caused by a single event. LSBUs represent the true failure rate of the part as seen from the application level.
- **Logical multibit upset (LMBU):** This refers to more than one bit failing in a data word caused by a single event. SECDED ECC algorithms are unable to correct LMBU events.
- **Single event latchup (SEL):** An SEL is a circuit latchup caused by a single radiation particle. An SEL may or may not cause permanent device damage but requires power cycling of the device to resume normal operation.

The following sections describe in detail the tests and analysis conducted by Cypress to qualify memory parts against atmospheric neutron particles.

4 Test Methodology

Cypress performs accelerated neutron SER measurements across all of its technologies and architectures. These tests are performed in collaboration with either iRoC Technologies (France) or JD Instruments (US) and involve industry experts in the field of soft error measurement. Neutron tests are performed at well-calibrated neutron beam facilities in Los Alamos (US), at TRIUMF (Canada), and at TSL (Sweden). Not every available Cypress memory device has actually been tested. Typically, the largest density devices in a given architecture are tested and the FIT rates are applied to the rest of the architecture family, given that the memory cell architecture is identical.

Cypress uses a state-of-the-art test algorithm for dynamic accelerated neutron SER testing. The algorithm identifies and isolates various SEE phenomena, such as SER or SEL events, and logs the failing addresses. Figure 3 and Figure 4 explain the experimental setup.

A set of up to six units selected from different lots is mounted on a PCB and irradiated simultaneously with neutron particles at the neutron beam facility. During the irradiation, the memory devices are read and written to continuously. The test board is sandwiched by flux calibration boards to extract the exact shielding factor. The neutron fluence is measured by a thin-film breakdown counter (TFBC) monitor and an ionization chamber. The TFBC monitor is calibrated for absolute measurements. The ionization chamber is calibrated against the TFBC monitor. The fluence is obtained by counting ionization chamber pulses and applying a proportionality coefficient. This neutron fluence is then used to scale down the failures to FIT rates in New York City (NYC). Details about accelerated neutron testing are in JEDEC standard JESD89A (October 2006).

Figure 3. Typical Experimental Setup for Accelerated Testing

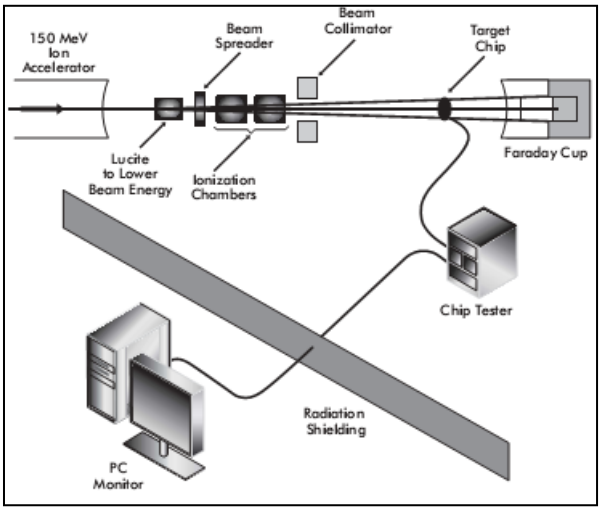


Figure 4. A Photo of the Test Board Sandwiched Between Calibration Boards

5 Test Conditions

The test conditions (Table 2) are judiciously chosen to test the memory device under all field operation conditions.

Table 2. Summary of Typical Neutron Test Conditions

Test Detail	Example
Facility	TSL, TRIUMF, LANSCE
Device Part Number	CY7C1513AV18
Package Type	165 BGA
Number of Devices	Six
Voltage Range	1.7 V, 1.8 V, 1.9 V
Temperature Range	25ºC, 85ºC, 125ºC
Pattern	CHB, ALL0, ALL1
Orientation	0º
Cycle Time	50 ns

Temperature: SER sensitivity with respect to temperature is a very important parameter, because failure rates can vary with temperature. At least two temperatures are applied during the neutron testing. Typically, the temperatures are room temperature (RT) and 85°C. JEDEC recommends testing the devices at elevated temperatures for SEL events. At Cypress we test our devices across the whole temperature range as specified in the datasheet, which for Sync SRAMs contains the SER FIT rates for room temperature and the SEL FIT rates for the maximum temperature. The following equation allows the calculation of the LSBU failure rates with respect to temperature between RT and maximum temperature:

- 90-nm SRAM technology: Sync, QDR®-II, QDR-II+
  LSBU[T°C] = LSBU[25°C] + 1.03*(T-25)
- 65 nm SRAM technology: QDR-II, QDR-II+
  LSBU[T°C] = LSBU[25°C] + 0.39*(T-25)

The above equations allow the adjustment of FIT rates for elevated operating temperatures. Note that the above temperatures are ambient temperatures.

Pattern: Test patterns are usually limited by the tester restrictions at the site. The standard test patterns are:
(1) checkerboard
(2) all “0”
(3) all “1”
(4) complementary checkerboard

Voltage: Because SER/SEL failure rates depend on the supply voltage, Cypress tests devices to the full V_{CC} range as specified in the datasheet. Almost all Cypress SRAM devices are internally regulated, so the external voltage does not result in any significant failure rate difference.

Frequency: The tests are conducted at the optimum test frequency as specified in the datasheet of the memory device. Because the actual test frequency is limited by the test setup, typical test frequencies are in the order of 10 to 30 MHz.

6 Neutron Beam Types

Two types of beams can be used for accelerated neutron SER tests. They are quasi-monoenergetic neutron (QMN) beams and spallation (or full-spectrum) beams.

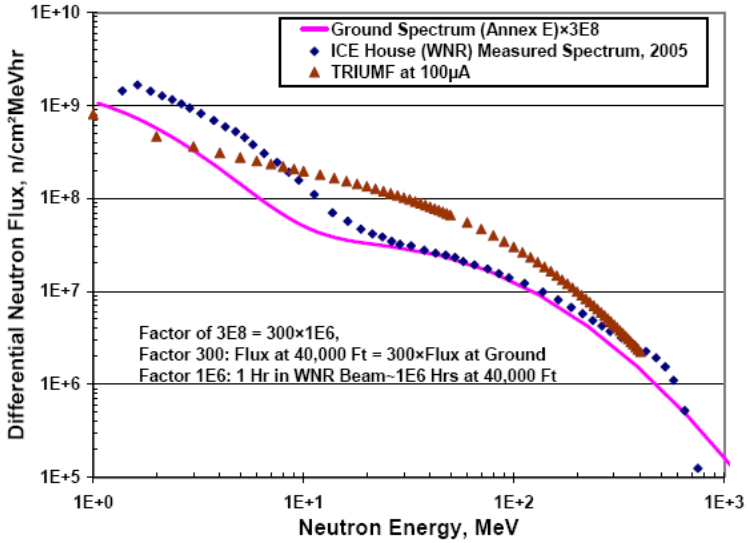
6.1 QMN Beams

QMN beams consist of neutrons at a specific energy of the spectrum. Monoenergetic beams offer the advantage of scaling the energy integral as close as possible to the terrestrial neutron flux. However, test campaigns are quite time-consuming because several energy runs have to be carried out to cover the whole spectrum. JESD89A (p. 44) specifies that measurements be done for at least four data points at four different energies to correctly estimate the neutron failure rates. The monoenergetic neutron beam at the Svedberg Lab (TSL) at Uppsala University in Sweden typically operates at energies of 20 MeV, 50 MeV, 100 MeV, and 180MeV.

6.2 Spallation Beams

A spallation beam is a single beam with neutrons spreading across all energies of the neutron spectrum. Neutrons between 20 MeV and 250 MeV are of primary interest. Some of the full-spectrum neutron beams that Cypress uses to qualify memory devices are at Los Alamos Neutron Science Center (LANSCE); TRIUMF in Vancouver, Canada; and Atmospheric-like Neutrons from thIck TArget (ANITA) at TSL in Uppsala, Sweden. The neutron beams at LANSCE and ANITA typically have a higher than normal fluence of neutrons, and the FIT rates obtained are about 45 to 70 percent higher than QMN FIT rates. Figure 5 shows a comparison of neutron spectra to the terrestrial ground spectrum.

Figure 5. Comparison of TRIUMF and LANSCE Spectra With Ground Spectrum



(Source: JESD89A, p. 39)

7 FIT Calculation

Typically, SER is measured in FITs. One FIT is a single failure in 10^9 device hours. It is always a good practice to specify the SER of any device in FITs/Mb or FIT/bit so as to normalize it over different densities. Moreover, because neutron flux varies with location and altitude, JESD89A specifies that sea level in NYC be the reference point for all SER FIT rates. Cypress follows the FIT rate calculation procedures exactly as outlined in JESD89A.

8 Confidence Limits

A common practice in this type of testing is to calculate confidence limits as a function of the number of events observed so that the experimenter can judge when to end the experiment. According to JESD89A, chi-squared statistics (which are a special case of the gamma function) are used to calculate 95-percent confidence limits on the failure rate obtained from these tests. JESD89A explains the detailed procedure on how to calculate the confidence intervals. For extremely low failure parameters, such as our SEL and LMBU measurements, a special form of the chi-squared statistic is applied. The 95-percent confidence limit is calculated using the following equation:

$$\text{LMBU(95\%CL)} = \chi^2(0.025,2)/(2 * \text{Mbit.hrs} * 1e^{-9})$$

…where Mbit hrs can be calculated to:

$$Mbit.hrs = \frac{TotalNeutronFluence}{NYCNeutronFlux} * Density$$

The TotalNeutronFluence represents the amount of neutrons to which all tested devices are exposed during the test campaign (total fluence). The FIT rate is then scaled to NYC flux conditions where 12 neutrons/cm^2 hr are assumed.

You can use the same equation to calculate the 95-percent confidence level for SEL. The confidence level intervals are decreasing with higher neutron exposure (fluence) or with testing a larger quantity of units.

The MAX FIT rate values specified in the Cypress datasheets or SER reports for neutron soft error immunity for the LMBU and SEL parameters are actually theoretical limits obtained by applying the previously mentioned formulas. No actual LMBU or SEL event is observed during accelerated neutron testing. During the entire campaign, the devices are typically exposed to 2–3 E9 neutrons/cm^2, which represents more than 10,000 years of neutron exposure at NYC.

9 Summary

High-energy neutrons generated from cosmic rays are the most dominant source of soft errors. Cypress follows state-of-the-art methodology to correctly measure and quantify the failure rates. Understanding the SER failure mechanism and knowledge of Soft Error Rate for specific SRAMs will help you design your system in a better way.

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Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	2753723	HRP / NYBP	08/26/09	New Spec.
*A	3741412	NYBP	09/12/2012	Updated Abstract (To clearly explain the scope of this document). Updated Introduction. Added SER Failure Mechanism. Updated Test Methodology (Included Figure 3 and Figure 4 and also improved explanation). Added Summary. Updated to new template.
*B	4097862	NYBP	08/16/2013	Added a table in Introduction section describing where to find SER data for each family of SRAM. Minor edits throughout. Updated to new template.
*C	5413906	PRIT	08/24/2016	Updated template
*D	5818121	AESATMP9	07/14/2017	Updated logo and copyright.

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