REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE Oct 1998	3. REPORT TYPE AND DATES COVERED Final Report

4. TITLE AND SUBTITLE

Cosmic Radiation at Aircraft Altitudes (neutrons) Influences on the Single Event Upset SEU Sensitivity for Low-Voltage Electronic Devices.

5. FUNDING NUMBERS

F6170897W0183

6. AUTHOR(S)

Prof Christer Svensson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of Linkoping
Department of Physics and Measurement Technology, Electron Devices
Linkoping 58183
Sweden

8. PERFORMING ORGANIZATION REPORT NUMBER

N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

EOARD
PSC 802 BOX 14
FPO 09499-0200

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

SPC 97-4036

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT (Maximum 200 words)

This report results from a contract tasking University of Linkoping as follows: The contractor will investigate single event upset phenomenon in low voltage microelectronics. The contractors will study and document the effects of cosmic radiation at the aircraft environment (neutrons).

14. SUBJECT TERMS

EOARD, Electronics and Electrical Engineering, Navigation,Comunications & Guidance, Physics, Space Environment

15. NUMBER OF PAGES

5

16. PRICE CODE

N/A

17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19, SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

97-4036

Final -Report on contract F61708-97-W0183

"Cosmic Radiation at Aircraft Altitudes (neutrons) Influence on the Single Event Upset (SEU) Sensitivity for Low-Voltage Electronic Devices."

This work will complement on-going ROME Laboratory Research projects in low-voltage electronics and single event effects in Avionics.

1. Introduction

It is now well known that modern microelectronic devices can suffer from Single Event effects (SEE) caused by cosmic radiation neutrons in the atmosphere. In 1993, Olsen et al. reported function failures in a new electronic equipment due to atmospheric neutron single event upsets (SEU) during regular intercontinental flights [1], similar effects in military aircraft were also reported by Taber and Normand in 1993 [2]. Attempts to correlate the SEU frequency with different ground based testing neutrons sources and flight measurements has been done [3]. In recent years, activities has also been initiated to assess the effects on aircraft crew [4] caused by high energy neutrons in the atmosphere.

The high energy neutrons undergo nuclear reactions with the silicon in the semiconductors. This reactions gives secondary charged particles which generates charged tracks in the semiconductor. If the charge is generated in an active part of a semiconductor device and the sum of the charge is equal or more than the device "internal critical charge" the state of memory cell may change as a result off the induced charge. This is observed as a bit error in e.g. a computer memory.

The modern microelectronics are continuously developed to shrunk in size and supply voltage, in order to obtain high density, high speed and low power consumption. That development implies smaller amounts of charge representing the information e.g. the internal critical charge become smaller for the devices. It is therefore assumed that the devices with low-voltage will be more sensitive than todays ordinary 5V parts.

This project is aimed at study the effects of "low-voltage" for device SEU- sensitivity due to cosmic radiation at aircraft environment (neutron) . The SEU measurement has been done on existing SRAM circuit specially designed for changing between different voltage (5-2 V). The tests has been performed at two different radiation sources a 14 MeV neutron single source and at an quasimonoenergetic 100 MeV neutron source.

2. EXPERIMENTAL.

A. *The Test Facilities*

Two different test facilities with capability to produce different neutron energy, 14 Mev and 100MeV, has been used in this experiments. The 14 MeV neutrons was produced from $^{2}D+^{3}T$ fusion reaction produced at Chalmers Institute of Technology (CTH) in Gothenburg. This reactions gives a neutron spectrum with a monoenergetic neutron peak at 14 MeV. The fluence is constant during test-time.

The Svedberg Laboratory (TSL) neutron beam facility [5] which produced 100 MeV neutrons is a cyclotron producing protons that impinge on the neutron production target. Neutrons are produced by the $^{7}Li(p,n)^{7}Be$ reaction, using a 100-800 mg/cm^{2} thick lithium target, enriched to 99.98% in ^{7}Li. After the target, the proton beam is bent into a well-shielded beam dump. The $^{7}Li(p,n)$ reaction produces a neutron spectrum consisting of a full-energy peak, having a width of 0.5-1 MeV (FWHM) and in addition a low are found in the main peak, while the remaining neutrons are due to the low-energy tail. A way to calculate the peak energy and it's contribution to SEU is described in [6] and the SEU dependence on the neutron energy is also described in [6].

B. The Test System

The SEU test system is based on five test boards with two devices mounted on each board. These boards are lined up in the neutron beam, radiating every device under test. The memory devices are programmed with three different patterns: all zeros, all ones and checker board (10101010..). The memory content is cyclically monitored during the irradiation. When upsets are observed , the correct memory content is rewritten to the device.

The experiments have been performed with a custom designed Static Random Access Memory (SRAM) with organisation 16384 x 1 bit. The memory was manufactured in a standard 0.8 µm bulk CMOS process from Austria Micro System International (AMS). The memory address space was splitted into two parts of equal size. The two parts consisted of memory cells of two different sizes which were selected by the most significant bit of the address. The memory cells are ordinary 6 transistor cells built from two cross-coupled inverters and two NMOS pass transistors. The chip was designed to operate at supply voltage 2-5 V in an active mode and downto 1 V in stand-by mode. These devices do not need to be placed into a stand-by mode before the voltage is reduced and readouts can be performed continuously. Layouts of the cells are shown in Fig.1.

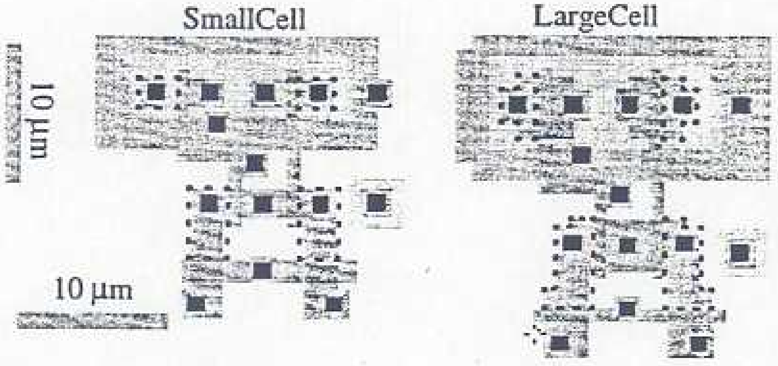


Figure 1: layout of the memory cells with marked sensitive regions (metal layers have been removed)

3. EXPERIMENTS AND RESULTS

The 10 SRAM devices has been initialised with a known pattern and the memory contents are periodically monitored during operation in the neutron source. During the tests at 14 MeV the supply voltage was changed in steps with 0.5V, between 2.0V and 5.0 V. Each supply voltage level was measured for 3 hours. The number of SEU was very low for the higher supply voltage both for the large and small cells. The large cell had less than 2 upsets for each of the supply voltage between 5 to 3 V, for the small cells the SEU-rate at 5V and 4V is negligible. In table.1 these supply voltages are marked with "---". At 100MeV the test was performed at two supply voltages, 2V and 5 V.

The dependence between the supply voltages and the *measured SEU-cross section* is shown in table.1. The SEU-rate is normalised to "1" at the highest "SEU-sensitive" supply voltage.

Table. 1

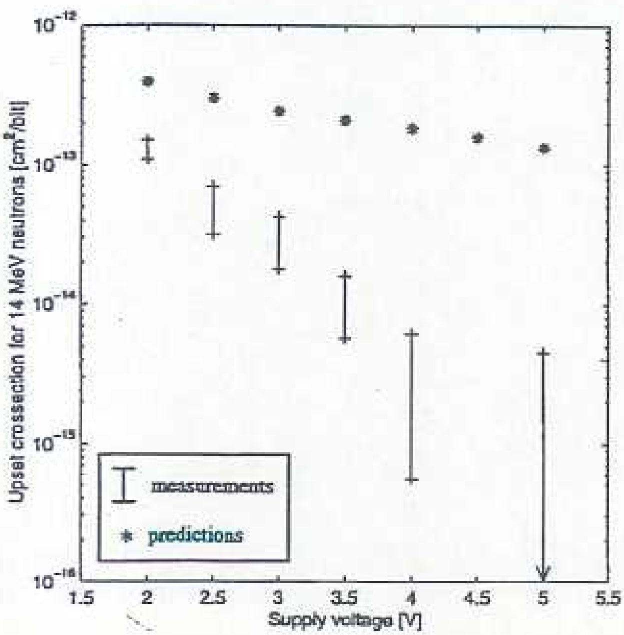
The dependence between the supply voltage and the measured SEU-cross section.
The SEU -cross section for the highest SEU-sensitive supply voltage is normalised to "1".

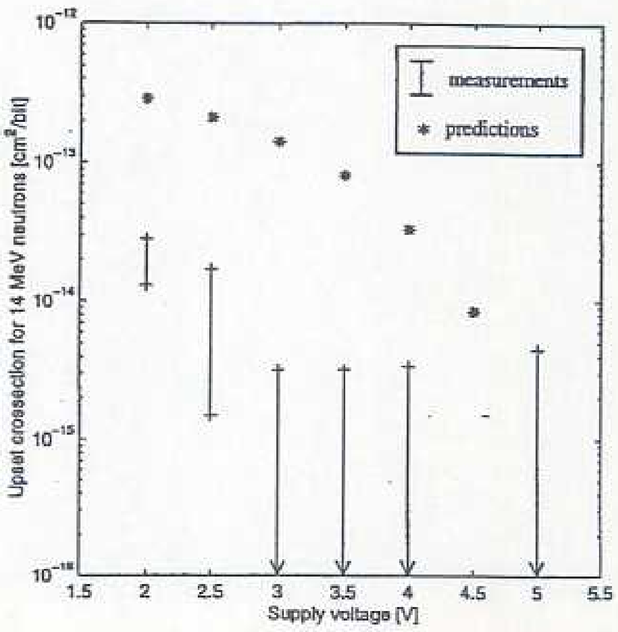
Cell size neutron energy	Supply voltage 5V	Supply voltage 4V	Supply voltage 3.5V	Supply voltage 3V	Supply voltage 2.5V	Supply voltage 2V
small cell, 14 MeV	---	---	**1**	**3**	**5**	**13**
small cell, 100MeV	**1**					**7**
large cell, 14MeV	----	---	---	---	**1**	**3**
large cell, 100MeV	**1**					**20 !!**

The test has been performed with different supply voltage for 14 MeV and 100MeV, this makes it difficult to compare the results between these to experiments. There is also a neutron energy dependence for the SEU-rate [6]and there is no compensation for this in table 1. Observe that this energy dependence also make it impossible to do a direct comparison between the SEU-cross sections at different energies presented in figures 2-5.

As expected, the 14 MeV measurements shows that the small cells in the devices is sensitive for higher supply voltages than the large cells. Nevertheless, comparisment between supply voltage at 2.5V and 2V for both the small and large cell shows a similar SEU-dependence. It is also interesting to notice that it seems to be big difference between the small and large cell at 100 MeV. One of the explanations, is the results for the large cell at 100 MeV which has very large uncertainties see figure 6. However, it does not explain the large differences as the test-results indicate.

SPICE- modelling has been used to do the critical charge simulation for the devices. This critical charge are then used in the Burst Generation Rate (BGR) model for calculating the SEU cross section. More detailed information are presented in [7]. A comparison between the calculated cross sections and the measured are shown in figures. 3-6





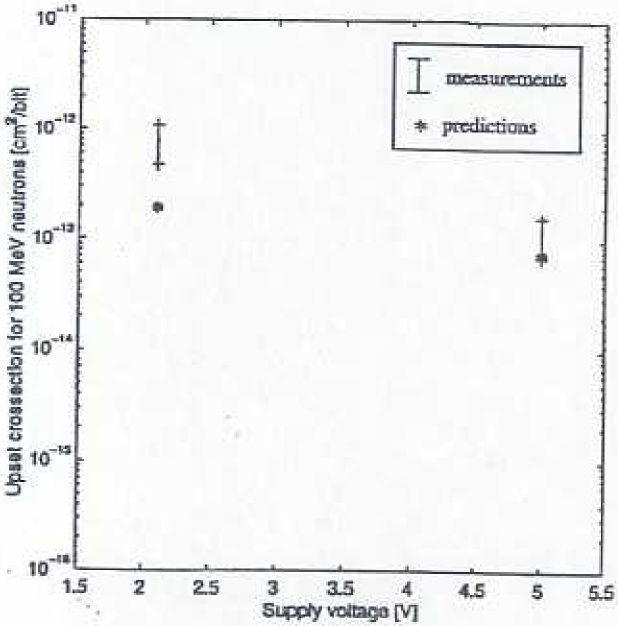


Figure. 5: Small cell, 100MeV neutron cross sections.

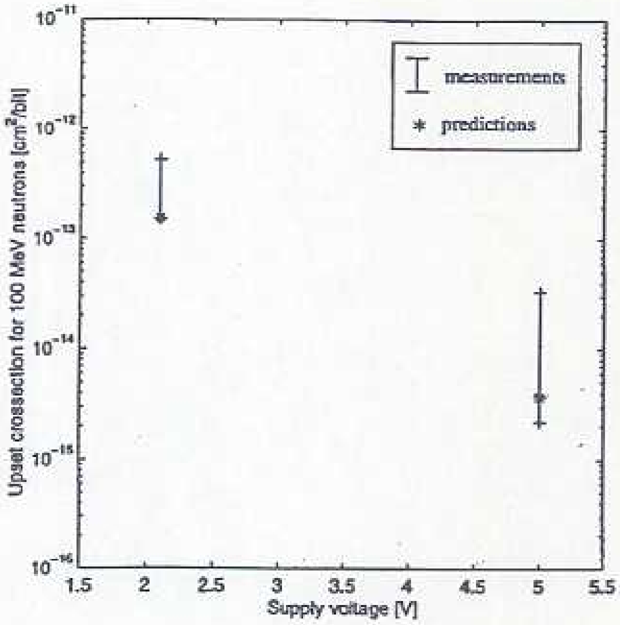


Figure.6: Large cell, 100MeV neutron cross sections.

As can be seen from the above figures, the simulations and the measured cross sections is not in so good agreement. The experiment results indicate that the predictions are over- estimated) and the supply voltage dependence is under- estimated for lower neutron energies (14 MeV). At 100 MeV the predictions underestimate both the cross sections and the supply voltage dependence. A more detailed discussion are presented in[7]

5 CONCLUSIONS

Study and understand the effects of "low-voltage" for device SEU sensitivity due to cosmic radiation at aircraft environment (neutron). The SEU measurement has been done on existing SRAM circuit specially designed for changing between different voltage (5-2V). The radiation sources used is a 14 MeV neutron single source and a 100 MeV quasimonoenergetic neutron source.

The SRAM devices ,10 parts, has been initialised with a known pattern and the memory contents are periodically monitored during operation in the neutron source. The supply voltage has been changed between 5 to 2 V during measurements.

Measured cross sections has been compared to predicted cross section by using SPICE-simulations to calculate the critical charged which has been used in the BGR-method for calculating the SEU cross section. This work are more described in detailed in[7].

The experiment indicate a stronger supply voltage dependence than predicted by a simple BGR-model. Measurements also indicate the supply voltage SEU cross section dependence to be dependent of the neutron energy.

6. REFERENCES.

[1] J. Olsen, P. E. Becher, P. B. Fynbo, P. Raaby, and J. Schultz, "Neutron-Induced Single Event Upsets in Static RAMS Observed at 10 km Flight Altitude," *IEEE Transactions on Nuclear Science*, vol. 40, pp. 74-77, 1993.

[2] A. Taber and E. Normand, "Single Event Upset in Avionics," *IEEE Transactions on Nuclear Science*, vol. 40, pp. 120-126, 1993.

[3] K. Johansson, P. Dyreklev, B. Granbom, M. C. Calvet, S. Fourtine, and O. Feuillatre, "In-Flight and Ground Testing of Single Event Upset Sensitivity in Static RAMs," *IEEE transactions on Nuclear Science*, vol. 45, 1998.

[4] B. J. Lewis, "Measurement of neutron radiation exposure of commercial airline pilots using bubble detectors," *Nuclear technology*, vol. 106, 1994.

[5] H. Condé, S. Hultqvist, N. Olsson, T. Rönnqvist, R. Zorro, J. Blomgren, G. Tibell, A. Håkansson, O. Jonsson, A. Lindholm, L. Nilsson, P. U. Renberg, A. Brockstedt, P. Ekström, M. Österlund, F. P. Brady, and Z. Szeflinski, "A facility for studies of neutron-induced reactions in the 50-200 MeV range," *Nuclear Instruments and Methods in Physics Research*, vol. A292, pp. 121-128, 1990.

[6] K. Johansson, P. Dyreklev, B. Granbom, N.Olsson, J.Blomgren, and P.-U. Renberg, "Energy-Resolved Neutron SEU Measurements from 22 to 160 MeV," *Accepted for publication* in *IEEE Transaction on nuclear science, Dec. 1998.*

[7] P. Hazucha, K. Johansson, and C. Svensson, "Neutron Induced Soft Errors in CMOS Memories Under Reduced Bias," *Accepted for publication in IEEE transactions on nuclear science, Dec. 1998.*