Mem. S.A.It. Vol. 79, 883

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Long Duration Balloon flights for the evaluation of radiation effects on electronic systems

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Abstract In this paper the proposal for a long duration polar flight program to study the radiation effects on electronic systems for space applications is presented. The arctic environment at balloon flight altitude and the expected soft error rate of selected candidate technologies areoutlined.

Key words. Long Duration Balloon Flights - Radiation Effects - SEU - Single Event Upset - Soft Errors - Polar Region

1. Introduction

Electronic systems for space applications have to cope with the effects induced by the radiation environment. As far as the ionizing radiation is concerned, they can be distinguished in single event effects and progressive charge accumulation damages. Both are responsible for failures affecting on-board computers: in particular single event effects are a major concern, since they may cause soft errors as temporary faults in memories and registers contents.

Long Duration Balloon (LDB) experiments in Polar Regions are subjected to severe environmental conditions similar to space, and thus are an ideal way for testing systems and technology. Moreover, they allow testing all components of a complex system simultaneously, as compared to accelerator ground tests. Also terrestrial applications are affected by radiation induced faults caused by neutrons, that may have serious consequences depending on the specific application field (e.g. medical, transportation). Polar stratospheric balloon experiments offer an effective option for performing accelerated tests on terrestrial electronics used in critical applications.

2. Radiation induced faults

In general terms, radiation induced faults can be distinguished in Total Ionizing Dose (TID) effect and Single Event Effect (SEE). The former is the progressive degradation of device performances due to accumulation of ionizing radiation, while the latter is the alteration of device functioning provoked by the traversal of a single particle in the matter. There are two primary ionization mechanisms: direct and indirect (or by nuclear reaction). The direct ionization is produced by heavy ions, while the indirect one is caused by protons and neutrons (Figure 1).

Traditionally, SEEs are classified according to their severity in soft and hard effects. Soft effects have a temporary (transient) and

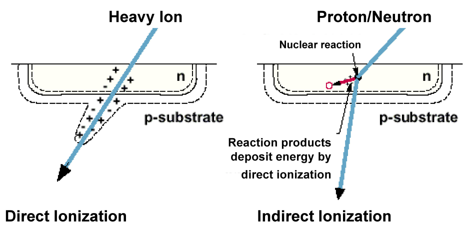

Figure 1. Direct and indirect ionization

non destructive nature. They are generically indicated with the term Single Event Upset (SEU) and produce a temporary alteration of the content of one or more memory cells (Multiple Bit Upset (MBU) or of the logical value of a circuit line (glitch). Hard effects, instead, provoke a permanent alteration of device functioning and are potentially destructive.

3. The radiation environment in the arctic

Due to the earth's magnetic field shape, the radiation environment in the stratosphere at the Polar Regions is an attractive location for evaluating radiation induced faults in electronic systems. For logistic reasons the arctic is the authors' preferred region for a long duration balloon flight.

In order to predict the behavior of microelectronic devices, as far as soft errors are concerned, neutrons and protons spectra at 30 km altitude in the arctic are necessary.

Various models are available to predict particle distributions. We have used QARM (QinetiQ Atmospheric Radiation Model), Lei (2004, 2006). It is based on incident particle spectra at the top of the atmosphere (e.g. CREME96, JPL91) and response matrices for secondary production and distribution (e.g. GEANT4, FLUKA). Moreover for the terrestrial neutrons we have used the IBM model developed by Ziegler, Ziegler (1998).

Results of calculations for fluxe estimation agree with the experimental data of the Lebedev Physical Institute of Russian Academy of Sciences (LPI RAS). Those data have been collected since 1957 from stratospheric measurements of cosmic rays in the northern polar latitudes, Stozhkov et al. (2007).

Figure 2 shows the resulting proton spectrum as obtained by the QARM model. The integral fluxes for energies greater than 1 MeV, 10 MeV, 100 MeV are respectively 2.68 $cm^2 s^{-1}$, 2.66 $cm^2 s^{-1}$, and 2.41 $cm^2 s^{-1}$.

The neutron spectrum by the same model is illustrated in Figure 3. The integral fluxes for energies greater than 1 MeV, 10 MeV, 100 MeV are respectively 3.67 $cm^2 s^{-1}$, 2.06 $cm^2 s^{-1}$, and 0.67 $cm^2 s^{-1}$.

Based on the above results, Table 1 gives an estimate of the expected particle (protons and neutrons) fluxes in the energy range of interest ($E > 10\,MeV$). For comparison, data for New York City, the ISS orbit and a geostationary orbit are also presented. Data for the ISS and the geostationary orbits are calculated by using the SPENVIS tool from ESA (ESA SPENVIS 4.5.0, http://www.spenvis.oma.be/). As it can be seen from the data, the total (neutrons and protons) flux in the arctic region at an altitude of 30 km ($\sim 5\,cm^2 s^{-1}$) is comparable to the total flux for the ISS orbit ($\sim 9\,cm^2 s^{-1}$).

Concerning the NYC location, it is interesting to notice the acceleration factor offered by an arctic LDB flight($\sim 2 \times 10^3$). This is a key parameter for on ground electronic life testing. The acceleration factor is the ratio between the estimated relative neutron flux (average value) at the actual location and the reference New York City flux.

4. The program

The objective of the program is to measure the effects of radiations on microelectronic devices and electronic systems, possibly associated to particle fluxes. The envisioned LDB arctic experiments are intended to complement radiation ground testing, also allowing the test of a computing system as a whole.

The proposed program consists of one arctic long duration flight per year for 3 – 5 years. The flight is characterized by a duration of about 15 days at 25 – 30 km altitude.

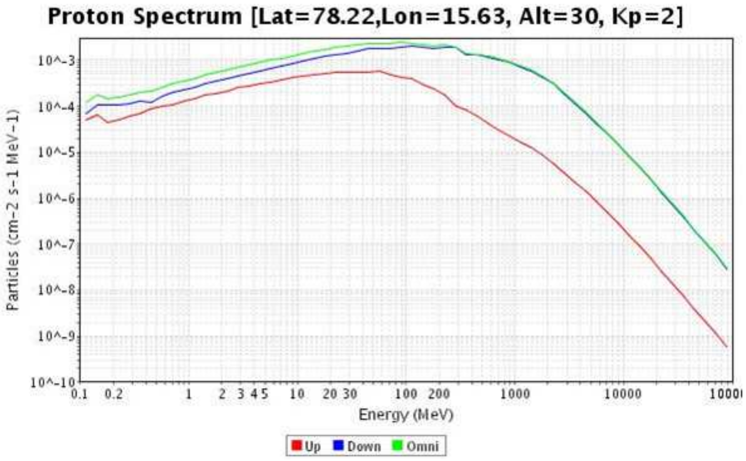

Figure 2. Proton spectrum at 30 *km* over the arctic

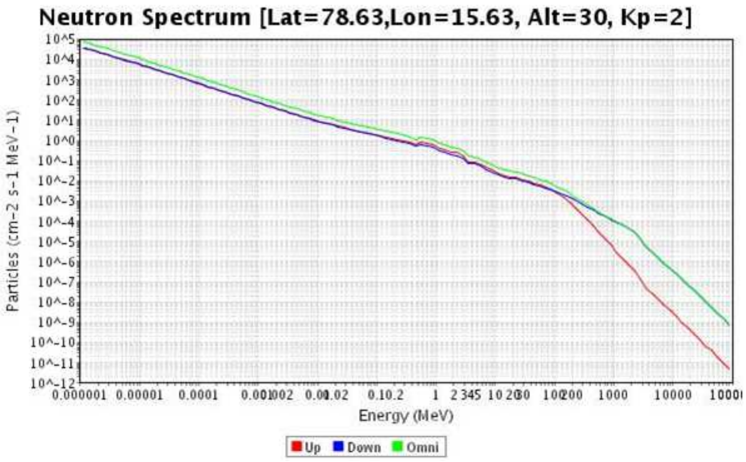

Figure 3. Neutron spectrum at 30 *km* over the arctic

Table 1. Neutron and proton fluxes estimate

Location	Proton flux ($cm^{-2}s^{-1}$)	Neutron Flux ($cm^{-2}s^{-1}$)	Tool
Arctic at 30 *km* altitude	~ 2.66	~ 2.06	QARM
New York City	~ 0.00	$\sim 2.68 \times 10^{-3}$	QARM
ISS orbit	~ 7.60 (AP-8)	~ 2.00 (AP-8)	SPENVIS
Geostationary orbit	~ 0.00 (JPL-91)	$\sim 2.12 \times 10^{2}$ (JPL-91)	SPENVIS

Candidate categories of technologies are memories, field re-programmable gate arrays, processors and digital signal processors.

Among memories, SRAM (Static Random Access Memory) devices are the most sensitive to soft errors. Other interesting types of memories deserving attention are FLASH and DRAM (Dynamic Random Access Memory). In particular a new generation of non volatile memory (FLASH) is requested for the

Table 2. Required number of devices for collecting 100 soft errors

	SRAM	FLASH	DRAM	SRAM-FPGA
device size [# *bit*]	16 Mbit	8 Gbit	1 Gbit	16 Mbit⋆
power dissipation [$mW/device$]	7	66	625	1650
$\sigma_{n,p}$ per bit [cm^2]	3×10^{-14}	5×10^{-18}	1×10^{-16}	3×10^{-14}
errors per bit(whole flight) [# $error/s$]	1.94×10^{-7}	3.24×10^{-11}	6.48×10^{-10}	1.94×10^{-7}
needed bit [# *bit*]	5.14×10^{8}	3.09×10^{12}	1.54×10^{11}	5.14×10^{8}
# *devices*	32	386	154	32
total power dissipation [W]	0.2	25.5	96.5	53.0

⋆ configuration memory size

Safeguard Data Recorder (SGDR) implementation, and the European Space Agency has planned the use of DDR (double data rate DRAM) memories in various missions.

Table 2 shows the number of devices required for collecting 100 soft errors in SRAM, FLASH, DRAM and SRAM-FPGA devices, considering a flight duration of 15 days, the predicted particle fluxes (neutrons and protons) of about 5 $cm^2 s^{-1}$, and the corresponding technology cross sections.

5. Conclusion

In this paper a program for LDB arctic experiments has been proposed. Environmental radiation conditions in an LDB flight over the arctic are similar to space and so ideal to test and validate systems and technologies both for space and terrestrial critical applications.

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