EXPERIENCE WITH THE ATLAS RADIATION TOLERANCE POLICY

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Abstract

ATLAS, as the other experiments, had to take into account the radiation effect on the electronics installed in the experimental cavern. It appeared very rapidly that putting in place a formal policy, based on constraints evaluation, standardised test procedures and reviews would help in getting sufficiently radiation hard electronics systems.

INTRODUCTION

The radiation constraints in ATLAS are very different for the electronics involved in the inner tracker than for the electronics located in the muon spectrometer or at the periphery of the detector on services balconies. For ten year operation at nominal luminosity, total ionising dose (TID) ranges from 1MGy to 7kGy while non ionising energy loss (NIEL) ranges from 2 10^{15} n.cm^{-2} to 2 10^{10}. The radiation levels were such in the tracker that the problem was taken into account in the very early phases of the designs as full custom electronics was needed and only a few radiation hard processes were available at that time. As of 1996, warning were addressed to those designing electronics for the calorimeters and the muon spectrometer and a very crude policy had been defined. At the same time RD49 was launched with the aims of studying the radiation tolerance of ASICs for LHC (leading to the development of special lay-out techniques for deep sub-micron technologies) and of coordinating the selection, evaluation and procurement of Commercial-Off-The-Shelf (COTS) components. However this was not sufficient to enforce good practices in the experiment and a formal policy was put in place.

POLICY DEFINITION

The goal of this policy is to obtain a good reliability with respect to radiation. The estimated lifetime of the components must cover the foreseen lifetime of the experiment or at least a large fraction of it. The rates of transient or destructive Single Event Effects (SEE) must be acceptable. The safety systems must remains always functional. All sub-systems had to follow the same rules and the tests to be performed were defined and based on recognised test methods (e.g. US-DOD MIL-STD-883E, ESE SCC basic spec. 22900 and 25100).

The policy [1,2] defines a strategy for components procurement, the radiation tolerance criteria's to be applied and the radiation test methods. It also provides a list of radiation facilities and some standard test report forms. The most important message is that every single component or system must be tested against radiation.

Procurement of components

It is important to take into account the radiation constraints early enough in the design phase and in particular to use components which are radiation hard enough.

The first step will consist in testing pre-selected (generic) components. The design will be done with those components. At the time of production the components will preferably be procured from single fabrication lots. In any case a sample of components bought for production will be tested.

Determination of the radiation tolerance criteria

The radiation constraints to be defined are:

-Total Ionising Dose (TID, unit: Gray);

-Non-Ionising Energy Loss (NIEL, unit: 1 MeV equivalent neutron per cm^2);

-Total fluence of hadrons having an energy higher than 20 MeV (unit: hadron per cm2) and which are esponsible for various Single Event Effects (SEE).

These radiation constraints have been simulated using GCALOR and FLUKA, for the various locations of electronics in each ATLAS Sub-systems.

Inaccuracies in the simulations result from inaccuracies in the event generation models, in the transport models and in the physical description of the detector, and from limited statistics (especially in the external regions of the detector). Some safety factors had to be applied to the simulated and are ranging from 1.5 to 5 depending on the type of radiation and location in the experiment.

Low dose rate effect can increase the damage produced by TID on CMOS, JFET or bipolar devices when irradiation is applied at low rate. This effect increases when the dose rate decreases; it becomes significant for dose rates below about 0.01 rad/s, depending on the technology [3,4]. The dose rate effect can be taken into account during the test by annealing at high temperature. If this is not been done during the tests, a safety factor should be applied on the TID constraint.

When using COTS, variation of radiation tolerance from batch to batch may result from process or equipment changes which do not affect the electrical features but which could degrade uncontrolled parameters such as radiation tolerance in standard technologies. In case the qualification of batches could not be done, a safety factor had to be applied on TID and NIEL constraints.

Test procedures and radiation facilities

Test methods, derived from DOD or ESA test methods [5-7] for CMOS devices and from ref. [8] for bipolar or BiCMOS devices were defined. They include an optional accelerated ageing that simulates the increase in damage produced by TID applied at low dose rate.

Based on [9], protons with an energy comprised between 60 MeV and 200 MeV enable seeking soft SEE as well as most of the hard and destructive SEEs. Latch-up or destructive events lead to the discard of the device.

Only radiation facilities providing a good dosimetry can be used.

ENFORCEMENT OF THE POLICY AND EXPERIENCE

This very strict policy has generated a substantial amount of work and also a substantial amount of complains…

It has been essential to have a dedicated person to the subject following the work done in the different sub-detector groups, giving advices and making sure the tests were properly done.

It has also been essential to get the support of the ATLAS management and to have the policy as an official ATLAS document.

The question of radiation hardness was specifically addressed during the review process.

Some actions were taken and tools put in place to make the people aware of the problems and to help them in their work. Tutorial sessions were done, common irradiation campaigns were organised, tools to compute the radiation constraint in any place of the experiment were developed (see http://atlas.web.cern.ch/Atlas/GROUPS/FRONTEND/radhard.htm#Radiation%20Constraints) and a data base to store the tests results. This data base was then extended to RD49. However the amount of available data is limited and its relevance is very often limited in time. (see https://oraweb.cern.ch/pls/RADHARDCOMPS/radhardcomps_public.frames).

Radiation hardness has proven to be a real burden and a lot of modifications in designs had to be done. A good example is what happened for the liquid argon calorimeter readout electronics. The initial design included a lot of COTS that proved to be marginal in terms of radiation hardness. Ten ASICs in either DMILL or 0.25µm CMOS technology had to be developed.

ARE WE SAFE?

We have some knowledge of how the different electronic systems will react to radiation. However there are still some uncertainties and worries.

The main uncertainty concerns the simulation. How accurate, pessimistic or optimistic have we been? The next months of running will probably give some answers to these questions.

In terms of total dose we are probably safe for a while and in addition total dose effects are not appearing as sudden failures and replacement of some components can be done.

The situation is slightly different for the SEE. The effects were measured and there is a knowledge of the failure frequency. However, the measurements give only some limits and it has not always been possible to make tests with a lot of components to increase the statistics. Counter measures have been implemented (triple redundancy, redundancy in DC-DC converters,…) and an SEE should only lead to the loss of a small fraction of the detector for a small period of time. However this will haven to be verified.

We can still have unexpected effects. One of them concerns the role of thermal neutron. It was discovered that the bipolar devices of one radiation hard technology is extremely sensitive to thermal neutron (when NIEL effects are tested with 1MeV neutrons). Recently we learnt that under certain conditions [10] these thermal neutrons can generate SEE. We have only taken into account hadrons of more than 20MeV energy for the SEE estimation and the amount of thermal neutrons is orders of magnitude higher.

CONCL USION

ATLAS had defined a formal policy on radiation tolerant electronics which defined tests and procurement procedures. To be enforced it required support from the ATLAS management and the dedication of one person to it. Specific actions and tools were taken and put in place.

REFERENCES

[1] M. Dentan, Overview of the ATLAS policy on radiation tolerant electronics, Proceedings of the 6th Workshop on Electronics for LHC Experiments, Krakow, Poland (2000)

[2] ATLAS Policy on Radiation Tolerant Electronics, EDMS ATC-TE-QA-0001, https://edms.cern.ch/document/113816/2

[3] A.H. Johnston et al., "Enhanced Damage in Linear Bipolar Integrated Circuits at Low Dose Rates". IEEE Transaction on Nuclear Science, Vol. 42, 1995, p.1650.

[4] A.H. Johnston et al., "Enhanced Damage in Bipolar Devices at Low Dose Rates: Effects at Very Low Dose Rates". IEEE Transaction on Nuclear Science, Vol. 43, No. 6, December 1996.

[5] US - DOD - MIL - STD 883E, test method 1017.2, 25 August 1983. Available on http://www.cern.ch/Atlas/ GROUPS/FRONTEND/WWW/milstd~1.pdf).

[6] ESA SCC basic specification no 22900, issue 4, April 1995. Available on http://www.cern.ch/Atlas/GROUPS/ FRONTEND/WWW/22900.pdf).

[7] ESA SCC basic specification no 25100, issue 1, Oct. 95. Available at http://www.cern.ch/Atlas/GROUPS/FRONTEND/ WWW/ 25100.pdf.

[8] O. Flament et al., "Ionizing dose hardness assurance methodology for qualification of a BiCMOS

technology dedicated to high dose level applications”. IEEE Transaction on Nuclear Science, Vol. 45, No. 3, June 1998.

[9] F. Faccio, M. Huhtinen, Nuclear Instruments and Methods in Physics Research A 450 (2000) 155 – 172.

[10] See F. Faccio’s presentation during the first R2E school http://indico.cern.ch/conferenceDisplay.py?confId=56796