ATLAS Technical Coordination
Radiation Hardness Assurance Working Group
Coordinator: M. Dentan.

Report of the

Fifth meeting of the ATLAS Radiation Hardness Assurance Working Group

CERN, 8 December 2000, 9:00-17:00.

Agenda:

I. New tools for Radiation Hardness Assurance
M. Dentan.

II. Pre-selection and qualification of radiation hard electronics for UX15
M. Dentan.

III. Example: Preparation of the ELMB radiation test campaign
B. Hallgren.

IV. Report from the ATLAS Detector Power Supply Working Group
C. Parkman.

V. Status of power supplies tests made by the CERN Pool
C. Rivetta.

VI. Radiation tests made by the sub-systems
- Overview of all the components to be qualified;
- Progress report on component pre-selection and qualification;
- Schedule of future radiation tests.

Participants:

Petr Sicho (Prague / ATLAS Pixels), Igor Mandic (Ljubljana / ATLAS SCT), Pierre Borgeaud (Saclay / ATLAS LARG), John Parsons (Nevis Columbia / ATLAS LARG), Philippe Grenier (CERN / ATLAS TILE), Vinnie Polychronakos (BNL / ATLAS CSC) Robert Richter (MPI Munchen / ATLAS Muon MDT), Werner Kubischta (CERN / ATLAS cryogenics), Friedrich Haug (CERN / ATLAS cryogenics), Ruggero Pengo (CERN / ATLAS Cryogenics), Stefan Haider (CERN / ATLAS Cryogenics), Harri Tyrvainen (CERN / ATLAS Magnet Control), Bjorn Hallgren (CERN / ATLAS TC-DCS), Martin Dentan (CERN/ ATLAS TC-Elec-RHA), Chris Parkman (CERN / ATLAS DPSSG), Claudio Rivetta (CERN Pool), Federico Faccio (CERN / EP-MIC).

I. NEW TOOLS FOR RADIATION HARDNESS ASSURANCE

I.1. The tools and how to get them:

The new ATLAS Radiation Hard Electronics Web Page[1] contains all the information, rules and tools which are necessary to apply the ATLAS radiation Hardness Assurance plan to the electronics which will be submitted to radiations in UX15 cavern:

- Overview of the ATLAS Radiation Hardness Assurance Plan;
- ATLAS Policy on Radiation Tolerant Electronics;
- Radiation Constraints, Safety Factors and Radiation Tolerance Criteria;
- Standard Test Methods and Standard Report Forms;
- Radiation Facilities and Radiation Campaigns Agenda;
- ATLAS Electronics Components Data Base;
- ATLAS Radiation Hardness Assurance Working Group (RHAWG);
- Tutorials on Radiation Effects;
- Workshops and Conferences;
- E.U. and U.S. Standard Radiation Tests Procedures;
- Related Web Sites.

The address of this web page is:
http://atlas.web.cern.ch/Atlas/GROUPS/FRONTEND/radhard.htm

I.2. Database:

To improve sharing radiation test results within the LHC community, ATLAS has decided to open the "ATLAS radiation hard electronics database" to all the other LHC experiments. It is now called "LHC Radiation Tolerant Electronic Components Database". The persons in charge of the database are Martin Dentan for ATLAS and Federico Faccio for CMS. RHA leaders in each ATLAS sub-system are invited to send their radiation test results to Martin Dentan. These test results may be written using the ATLAS standard test reports forms available on the web (recommended), or using any other format (home made test report, IEEE publication, etc.).

I.3. Radiation test agenda:

An interactive agenda is available on the web. It enables sub-systems to know which radiation tests are planned by other groups in the coming months, or to announce their own coming radiation tests. The aim of this agenda is to facilitate sharing radiation facilities between sub-systems. RHA leaders in sub-systems are invited to consult this agenda[2] (no password required) and to search for sharing radiation facilities with other sub-systems. If no sharing is possible, they are invited to book a radiation facility by asking directly the facility contact person whose name is given in the lists of radiation facilities[3] (available on the web), and then to record their booking in the agenda[4] (a password for entering data will be granted to RHA leaders from each sub-systems).

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[1] http://atlas.web.cern.ch/Atlas/GROUPS/FRONTEND/radhard.htm
[2] http://oraweb01.cern.ch/atlasradag/owa/Q_CERN_AGENDA.queryList
[3] http://atlas.web.cern.ch/Atlas/GROUPS/FRONTEND/radhard.htm#Radiation Facilities
[4] http://oraweb01.cern.ch/atlasradagadm/owa/ATLAS_RAD_TST_AGENDA$.startup

I.4. RADWG:

A lot of radiation test results are published in the web site of the LHC Radiation Working Group (RADGW). The address of this site can be found in the ATLAS Radiation Hard Electronics Web Page, section 11: "related web sites".

I.5. Simulated Radiation Levels and Safety Factors:

The following improvements have been requested by ATLAS sub-systems:

- Muon CSC 1 region: mistake => already corrected;
- TILE, LVPS: R=410 & Z=300 => values of TID, NIEL, SEE?
- Pixels: *by domains of 1cm x 1cm* => values of TID, NIEL, SEE?
- CAVERN: by domains of 1m x 2-3m => values of TID, NIEL, SEE?
- Each (R, Z) domains in ATLAS => are there hot spots? Values if any?
- Each (R, Z) domains in ATLAS => are there improved SFsim values (in particular for the inner detectors)?
- ATLAS and UX15 => TID, NIEL & SEE maps are requested, up to R = 16.7 m (footbridge along the wall between UX15 and USA15) and Z = 28 m (UX15 apse).

These requests have been submitted to Mike Shupe, who is responsible for the simulation of ATLAS radiation environment.

II. PRESELECTION AND QUALIFICATION OF RADIATION TOLERANT ELECTRONICS FOR UX15

II.1. Most important rule:

All the electronics that will be installed in UX15 cavern – inside or outside the ATLAS detector – must be qualified to resist to the radiation constraint expected during its foreseen operation duration.

This rule determines the strategy for procurement of all the electronics intended for UX15, given in the ATLAS Policy on Radiation Tolerant Electronics Revision 2.

II.2. Strategy for COTS or rad-hard ASICs procurement:

Procurement of radiation-tolerant Components Off The Shelf (COTS):

1. Determine the Simulated Radiation Level (SRL) in the application;
2. Calculate the Radiation Tolerance Criteria (RTC);
3. Pre-select generic components (radiation tests);
4. Purchase[5] batches of components;
5. Qualify batches (radiation tests).

Procurement of radiation-hard ASICs:

1. Determine the Simulated Radiation Level (SRL) in the application;
2. Calculate the Radiation Tolerance Criteria (RTC);
3. Select a radiation hard technology (guaranteed features);
4. Develop a prototype ASIC;
5. Qualify the radiation hardness of the ASIC (radiation tests);
6. Purchase batches of qualified ASICs[6]

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[5] Whenever possible, qualify batches by sampling before purchasing them.

[6] It is recommended to check the radiation tolerance of production batches by sampling. This final verification can be made with 60 MeV protons in order to check TID, NIEL and SEE at the same time.

Results of pre-selection and qualification tests are part of Preliminary Design Reviews (PDRs) and of Production Readiness Reviews (PRRs).

II.3. Pre-selection and qualification of electronics for UX15 :

Practically, radiation test campaigns for pre-selection of generic components or for qualification of batches of components to be installed in UX15 must be done as follow:

1. Search for existing data (ATLAS Radiation Hard Electronics database);
2. Determination of the Radiation Tolerance Criteria (RTC);
3. Selection of a radiation facility (cf. section I.3. in this report);
4. Preparation of the test bench;
5. Preparation of the samples to be irradiated;
6. Irradiation (ATLAS standard test procedures);
7. Analyse of the results;
8. Decision (acceptance or rejection of the generic component or of the batch);
9. Data recording (database: cf. section I.2. in this report).

A summary of these steps is available on the web[7].

III. EXAMPLE: PREPARATION OF ELMB RADIATION TEST CAMPAIGN

ELMB (Embedded Local Monitor Box) will be used by several ATLAS sub-systems. It contains CMOS, bipolar and opto-coupler devices. It will be qualified by DCS for operation in a radiation environment comparable to that of Muon MDT detector (barrel 1). Taking into account the safety factors, the Radiation Tolerance Criteria (RTC) at this location are:

- RTC_{tid} = 33 krad in 10 years;
- RTC_{niel} = 6.0E11 n/cm2 (1 MeV equivalent) in 10 years;
- RTC_{see} = 1.1E11 h/cm2 (> 20 MeV) in 10 years;

ELMB contains 49 components representing 20 different types of components. The list of these components is available on the web[8]. Radiation tests will be made using entire ELBM boards. For practical, economical and speed of testing reasons, measurements will be made on line during irradiation. ELMB is made of 3 independent parts (CAN, micro-controller and ADC) which simplifies the fault finding.

- TID tests: Preliminary test will be made in January or February 2001 at CERN X-ray facility on one or two prototypes available now. A test bench will be developed in Q1 2001 and tested in April 2001. Full TID tests will be made in May 2001 at CERN/GIF or at Pagure (Saclay). For these tests, 20 ELMBs will be online tested via CANbus and SCADA software. Complete on-line tests will be made on analog and digital inputs and outputs.
- NIEL tests will be made on 20 ELMBs in May 2001 at Prospero (Dijon). The same measurements as for TID tests will be made for NIEL tests.

[7] http://atlas.web.cern.ch/Atlas/GROUPS/FRONTEND/WWW/RAD/RadWebPage/RHAWG/Trsp081200/Dentan081200.pdf
[8] http://atlas.web.cern.ch/Atlas/GROUPS/FRONTEND/WWW/RAD/RadWebPage/RHAWG/Trsp081200/Hallgren081200.pdf

- SEE tests: They will be made in May 2001 on 4 boards irradiated with 60 MeV protons in Louvain-la-neuve. For SEU tracking, a special software will be used to detect errors in memories and registers. For SEL tracking, the current in each separate part will be monitored. A built-in protection will help bipolar regulators with current limitation at x4 normal value.

IV. REPORT FROM THE ATLAS DETECTOR POWER SUPPLY STEERING GROUP (DPSSG)

The ATLAS Detector Power Supply Steering Group has been set up with the following terms of reference:

1. To receive and disseminate information to the ATLAS community;
2. To oversee and co-ordinate joint R&D;
3. To organise procurement in collaboration with the sub-detector groups as well as with other LHC experiments, as appropriate;
4. To act as a point of contact with CERN EP Division and with industry.

Its membership consists of representatives from:

- ATLAS subdetector groups, (6);
- DCS (1);
- Electronics co-ordination (1) – Convenor;
- CERN EP Division ESS Group - "Pool" (1).

During its first formal meeting held on 5 December, the SG looked at the constraints which will be put on the power supply design and implementation by the detector's layout in terms of cable dimensions and length, the space available for on-detector power regulation, as well as problems of accessibility, not forgetting radiation and magnetic fields.

The on-going work on radiation effects was summarised and the SG was happy to lend its support to the Rad-Tol WG's coordination efforts, in particular the availability of information on component performance in the upcoming database.

The effort being put into basic R&D on a modular approach to LV power supplies by the TileCal group was presented and could serve as a model for future work towards a greater commonality in the PS design and implementation. The additional possibility of commonality in the monitoring and controls was also discussed. Apart from the obvious advantages of a common approach for procurement and long-term support, financial constraints are looming and may be an overriding factor. In addition, the possibility of aid from CERN for an eventual common project with one or more of the other LHC experiments was also seen to be attractive.

The Steering Group will start making informal contacts with industry in the New Year with a view to understanding the possibilities of support for R&D and eventual procurement as well as how best to help such efforts reach reasonable conclusions.

The signs of a willingness amongst the majority of the sub-detectors to work towards a maximum of commonality and cooperation in the R&D phase was evident, but needs to be reinforced to avoid duplication of effort at all stages of the work towards the final solutions. Progress will be review at the SG's next meeting in February.

V. STATUS OF POWER SUPPLY TESTS MADE BY CERN POOL, ATLAS AND CMS

These tests are part of a study of power supplies started in 1998 by CERN Pool (Bruno Allongues), CMS (Claudio Rivetta) and ATLAS (Robert Richter). Two approaches are followed:

Approach 1:
Search for a commercial power supply, which may stand with the radiation constraint without any modification. Search for the best operating condition with respect to radiation effects. If possible, qualify the power supply with the best operating conditions, for use in the expected radiation environment.

Approach 2:
Identify commercial power supplies exhibiting promising radiation hardness. Identify its critical components with respect to radiations. Search equivalent components exhibiting a better radiation hardness. Qualify equivalent components with respect to radiation hardness. Replace weak components by qualified components. This strategy applies only to power supplies on which critical components can be replaced.

Other studies must be done on the tolerance of power supplies with respect to the magnetic field and on EMI problems. Finally, power supplies must comply with the ISO standards (safety, reliability, EMI, …).

SEE tests were made in August and October 2000 with 60 MeV protons at Cyclone, U.C. Louvain-la-Neuve (Belguim) on six DC-DC converters:

Converter	Output voltage	Output current	Input voltage	Reference
Melcher[9]	5V	16A	190-350 VDC/VAC	LS 1001-7
Delta[2]	6V adj.	13A	190-350 VDC/VAC	75 SX 5
CNB[2]	6V adj.	3A	190-350 VDC/VAC	CN-17B "CERN durci"
Vicor[10]	5V	40A	250-425 VDC	V375B5C200A
Vicor[3]	12V	25A	250-425 VDC	V375B12C300A
Vicor[3]	12V	20A	180-375 VDC	V300B12C250A

These tests were made up to few 10^{10} p/cm^2 in order to avoid total dose effects (supposed negligible in actual operation). The proton beam was focused successively on the various elements of the power supplies in order to identify weak components.

Tests made with a relatively low output current give promising results (see report on the web). However, additional tests on more samples and with larger output currents are necessary to estimate the MTBF under radiation constraint in more realistic load conditions.

Vicor power supply cannot be modified. Special operating conditions (200V input; 8V/20A output) which may enable their use in LHC radiation environment are currently under study. Such output voltage is compatible with 20 m cables between the power supply (outside the detector) and a rad-hard voltage regulator (inside the detector), which requires 6 volts input.

[9] Replacement of critical devices is technically feasible, and the company agree to discuss on possible changes in the architecture.
[10] Replacement of critical devices is not possible, and the company doesn't want to make any changes in the architecture.

SEE tests were made in August and October 2000 with 60 MeV protons at Cyclone, U.C. Louvain-la-Neuve (Belgium) on four power devices:

Power device	Type	Manufacturer	Maximum bias	Used in
MTP6N60E	Power NMOS	Motorola	600V 6A	VICOR DC-DC conv.
IRFBC40LC	Power NMOS	Int. Rectifier	600V 6A	VICOR DC-DC conv.
BUZ50E	Power NMOS	Siemens	1000V 2A	DELTA DC-DC conv.
30CPQ100	Schotky diode	Int. Rectifier	100V	MELCHER DC-DC conv.

These tests enable one to estimate the SEE cross section (σ_{see}) without destroying the tested devices. Present results show large differences in σ_{see} between devices. They confirm that devices designed for high voltage operations and operated with a de-rated voltage have a significantly lower σ_{see} than devices designed for lower voltage operations. For instance, 3 NMOS BUZ50E operated at 450V may provide 3 x 2 = 6A and would exhibit a σ_{see} < 3 x 0.5E-11 = 1.5E-11 cm^2, which is much lower than the SEE cross section of IRFBC40LC operated at the same voltage (few 8E-9 cm^2).

This approach may lead to the qualification of power devices with respect to radiation effects.

Another known critical device is the opto-coupler, which is sensitive to NIEL. A study of several opto-couplers has shown that HP6N138 / HP6N139 is more robust to NIEL than most of the other devices.

The extension of this approach to the other weak parts of power supplies (identified by tests made on full power supplies) may lead to the qualification of replacement components with respect to TID, NIEL and SEE. Such components may replace weak parts in commercial converters in order to get radiation hard power supplies.

VI. RADIATION TESTS MADE BY ATLAS SUB-SYSTEMS[11]

Pixel

- ASICs development: in progress. Should be completed in 2001.
- ASICs pre-selection: should be completed in 2002.
- COTS for interlock box: pre-selection to be done in June 2001; qualification to be done in December 2001.
- Summary of ASICs developments and radiation tests:
  - FED (DMILL): yield issues related to dynamic digital circuitry, under investigation by ATMEL. Back-up solution under study (IBM). Pre-selection in 2002.
  - DORIC (DMILL): design problem, to be corrected. Pre-selection in 2002.
  - VDC (DMILL): development completed in 2001, pre-selection completed in 2002.
  - MCC (DMILL): development completed in 2001, pre-selection completed in 2002.
  - VCSEL and PIN diode: radiation tests made by SCT collaboration. Additional tests (higher radiation levels) to be done by Pixel collaboration.

[11] Transparencies presented by ATLAS sub-systems are available in section 7.3 of the ATLAS Radiation Hard Electronics Web Page: http://atlas.web.cern.ch/Atlas/GROUPS/FRONTEND/radhard-draft.htm#RHAWG

SCT:

- ASICs development: completed.
- ASICs pre-selection: completed.
- ASICs qualification: scheduled in 2002-2003.
- Summary of ASICs developments and radiation tests:
  - ABCD3T (DMILL): X-rays radiation tests at low dose rate in progress. Yield issues, under investigation by ATMEL.
  - DORIC (AMS): development and pre-selection completed.
  - VDC (AMS): development and pre-selection completed.
- Results of SEU tests made on ABCD with 24 GeV protons (PS/T7) are comparable to those made with 200 GeV pions (PSI). *This result constitutes a first qualification of PS/T7 facility for SEE testing.*

TRT:

- ASICs development: in progress. Should be completed in 2001.
- ASICs pre-selection: in progress. Should be completed in 2001.
- ASICs qualification: scheduled in 2002-2003.
- Summary of ASICs developments and radiation tests:
  - ASDBLR: present version is working.
  - DTMROC: present version is working. Back-up version (IBM) under study.

LARG:

- ASICs development: in progress. Should be completed in 2001.
- ASICs pre-selection: in progress. Should be completed in 2001.
- ASICs qualification: scheduled in 2002.
- Summary of ASICs developments and radiation tests:

- SCA (DMILL): pre-production submitted W46 (2000); delivery W14 (2001).
- SCA controller (DMILL): prototype submitted W47 (2000), delivery W15 (2001). Back-up version (IBM) under development.
- Other DMILL chips (Gain selector, SPAC slave, Configuration controller, MUX, BiMUX, DAC, Low offset amplifier, Control Logic, Delay, TTCRx): Prototypes should be delivered by ATMEL in W05 (2001).

- COTS pre-selection in progress (TID and NIEL tests done; SEE tests to be done).

TILE:

- COTS pre-selection in progress (TID and NIEL only, made on few samples only);
- Summary of pre-selection tests made on TILE boards:
  - ADC integrator, 3-in-1, Adder, HV-micro, HV-opto: TID and NIEL preselection tests are considered as completed. SEE pre-selection tests to be done.
  - Mother board, digitizer, S-link & interface: TID and NIEL preselection tests in progress or foreseen in the near future. SEE pre-selection tests to be done.
- Some productions already started
- Comments from the RHA Coordinator (M. Dentan):
  - Due to the very small sampling (1 single sample irradiated, in some cases) and to the missing SEE tests, the pre-selection cannot be considered as fully conclusive. This induces a risk on the already started productions.

- To make sure that the all the Tile Cal electronics will resist to the foreseen radiation constraint, full radiation hardness qualification (TID, NIEL and SEE tests, using sampling and test methods recommended in the ATLAS Policy on Radiation Tolerant Electronics revision 2) must be done in 2001 on production batches.

<u>MUON CSC</u>

- A list of the CSC electronic components is available on the web[12].
- Electronics qualification status:
  - Majority of electronic components is common with LARG, and SRLs are similar to LARG. Hence, electronics pre-selection and qualification will be done jointly by LAR and CSC (already much progress from LARG).
  - Pre-selection to be done in 2001.
  - Pre-ampli / shaper: encouraging TID results to 1 Mrad.
  - GLINK: SEE test set being constructed at UCI; tests expected to start in Q1-2001.
  - Multiplexor: beginning to prototype with FPGAs; still have to choose rad-tolerant technology (discrete shift register or ASIC).

<u>MUON MDT</u>

- Pre-selection will start in 2001, using ATLAS standard test methods.
- Organisation and schedule will be presented during the Preliminary Design Review (PDR) which will take place on February 22, 2001.

<u>DCS:</u>

- ELMB electronics: preselection scheduled Q1 2001 (see section III in this report).

<u>Cryogenics:</u>

- Pre-selection to be done in 2001.
- Strategy:
  - Remove as much electronics as possible from UX15;
  - Use radiation test results from LHC group (R.Rauch) whenever possible.

<u>Magnet Control:</u>

- No radiation test made.
- Magnet control will follow the cryogenics sub-system pre-selection and qualification of components.

<u>Crane, Elevators:</u>

- Electronics will not be subject to SEE, because it will be shut down when the beam will be on.
- Electronics may be sensitive to the total ionising dose or to the neutron fluence it will receive during 10 years of operation. A choice must be made between several possible strategies: 1/ preselect and qualify electronics for 10 years of operation (probably too expensive); or 2/ qualify electronics for 1-3 years of operation and foresee its replacement after this time; or 3/ (…). This radiation hardness assurance strategy is part of PDRs and PRRs.

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[12] http://atlas.web.cern.ch/Atlas/GROUPS/FRONTEND/WWW/RAD/RadWebPage/RHAWG/Trsp081200/Polychronakos081200.pdf