

Radiation Hardness and Magnetic Field Tolerance of CAEN “CMS Tracker” SASY.

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Abstract

Results are presented on the radiation and magnetic tests carried out in May and July 2003 on the SASY power supply developed by CAEN for the CMS Silicon Tracker Detector. In particular, using the test equipment developed at Torino INFN laboratory Single Event Upsets both on the analogue and in the digital circuits of the power supply have been detected online. The experimental procedure is described at length and the results are discussed in the perspective of 10 years LHC running.

I. INTRODUCTION

An important fraction of the electronics for the LHC experiments will be placed underground close to the detectors, in an area where relevant fluxes of charge and neutral particles and not negligible residual magnetic field are expected.

The radiation levels foreseen in the underground area for the CMS experiment are shown in detail in [1] and they strongly depend on the particular location where the device will be placed. About 2000 power supply complex channels (PSU) will be installed on the balconies around the barrel sector of the CMS detector, at a radial distance of about 10 meters from the beams interaction point. At this location, we expect to integrate, over 10 years LHC running at nominal luminosity, a neutron flux of $1.2 \times 10^{11} \text{ cm}^{-2}$. Charge particle contribution is lower by 3 orders of magnitude, resulting in an integrated dose of only 0.40 Gy over the same running period. The neutron energy spectrum ranges from thermal values up to few hundred MeV, spanning more than 9 orders of magnitude.

The magnetic field at the PSU location is expected to be less than 1000 Gauss. In a recent workshop [2] the value has been set around 400 Gauss.

Radiation, and in particular neutron exposure, remains the main concern for the functionality of underground electronics, in particular for their capability of causing Single Event Upsets (SEU) in the electronic chips with consequent malfunction or even breakdown of the devices. For a comprehensive illustration of the risks from SEU in a hadron accelerator environment see e.g. [3].

We remind here that SEU are caused by a high energy deposit in a small volume of an electronic chip. The critical energy, i.e. the energy required to trigger a SEU, is component dependent and typically ranges between few hundred keV and few MeV. The reaction can be initiated by secondary particle emission, and in particular slow ions recoil, produced in inelastic nuclear reactions of hadrons on silicon. This is the dominant process when the hadron energy is above 20 MeV. In the range between 2 MeV and 20 MeV also the elastic nuclear reaction plays a role in producing SEUs although the total cross-section of the process is smaller than in the high energy case. Although thermal neutrons are not expected to be an important source of SEU at LHC, some care should be paid for ICs with high concentration of ^{10}B . This has a 3.8 kb thermal cross-section for the reaction $^{10}\text{B}(n,\alpha)^7\text{Li}$ which releases 2.8 MeV of energy shared between the two fragments, enough to upset the device.

The measurements described in the following sections have been done not on a single component base but studying the behaviour of the SASY power supply as a whole. Although smeared by the complexity of the system, SEUs have been detected both in the analogue and in the digital part of the SASY board.

II. NEUTRON IRRADIATION TEST

The radiation tests discussed in this paper have been carried out on May 26-th 2003, using the T2 neutron beam

line facility at UCL (Louvain-la-Neuve). Neutrons are obtained converting 50 MeV deuterons on a berillium target.

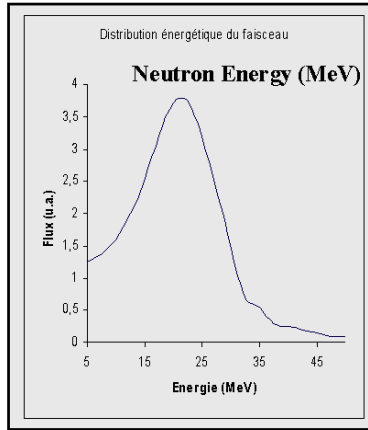


Figure 1: T2 neutron beam energy spectrum (courtesy of UCL). The component below 5 MeV is not monitored.

The neutron energy spectrum is shown in Figure 1. This qualitatively reproduces the neutron spectrum at the particular location where the power supply units have to be installed [4].

The experimental setup used in the measurement is shown in Figure 2. The power supply unit, labelled SA2011, was mounted transverse to the beam at a distance of about 85 cm from the target. The same crate contained also the control board placed at 100 cm from the target. The beam cone radius at the board locations was about 10 cm, enough to illuminate the boards in one go, with an 85% level of homogeneity.

The irradiation was done in sequential steps: first we integrated 1.2×10^{11} n/cm² at the PSU board position, next we brought also the control board at the same irradiation level and finally we kept running until we reached an integrated flux equivalent to 30 years LHC.

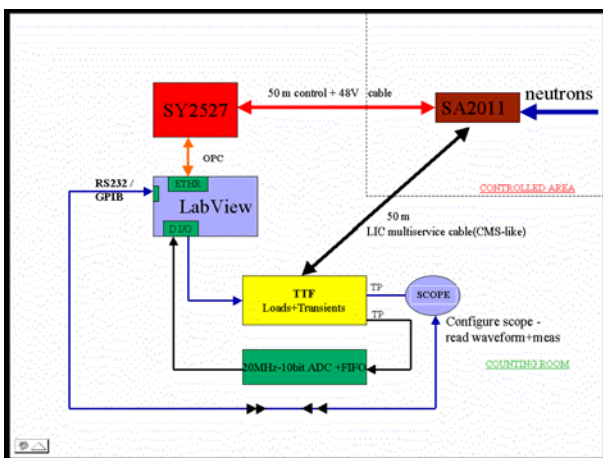


Figure 2: The experimental setup used during the test at Louvain-la-Neuve

The SA2011 communicated via 50 m long cable with the system main controller SY2527 that was used to switch on and off the low voltage and high voltage channels and to monitor the outputs with 1 Hz refresh frequency. Moreover it also allowed to check the communication status with the remote branch and to verify the 48 V supply of the remote crate.

Using a 50 m CMS standard low inductance cable, the PSU outputs were connected to the test fixture (TTF) developed at Torino INFN laboratory (see Figure 3). It consists of a programmable, low noise, electrically floating board, capable of performing quality tests of the PSU. Stability test, noise characteristics, over current and over voltage dynamics and the remote sense performance can be checked using this fixture.



Figure 3: The dynamic load test fixture developed at Torino -INFN

During the radiation test the TTF has been used both to produce dynamic load variations and to study long term stability at a fixed power output.

The PSU channels were continuously monitored at the loads using a TDS3034B digital scope readout by a PC via GPIB. Moreover the 1.25 V PSU line was also sampled at 1MHz with a digitizer board developed at Torino INFN laboratory (see Figure 4).

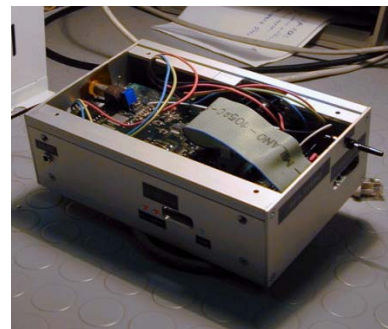


Figure 4: Torino digitizer to detect instabilities on the PSU DC output lines

The board was used in a triggered mode with 50 mV threshold and 2 mV resolution. The idea was that if a Single Event Upset occurred at the PSU level, some instability could appear at the DC output.

During data taking 29 “spike-like” events were recorded, 9 of those in the 10 years LHC limit. One example is shown in Figure 5.

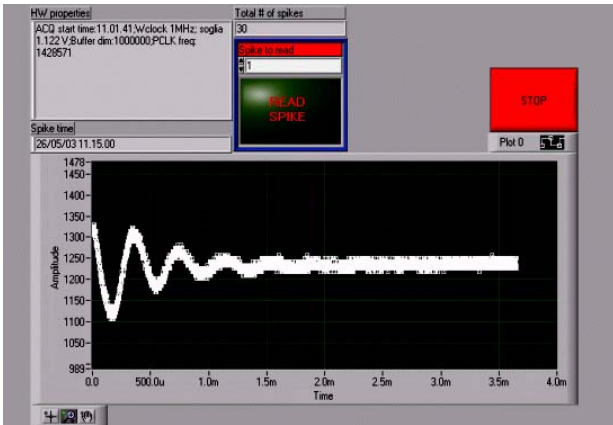


Figure 5: SEU effect on the 1.25V line

The oscillation period is related to the 2 kHz bandwidth of the crowbar circuit used on the CAEN SASY board to limit voltage instabilities. A maximum amplitude of 290 mV peak-to-peak has been observed. For comparison the typical ripple on the 1.25V line is below 10 mV peak-to-peak.

The CAEN SY2527 main controller with its 1 Hz refresh time, was not able to record such events.

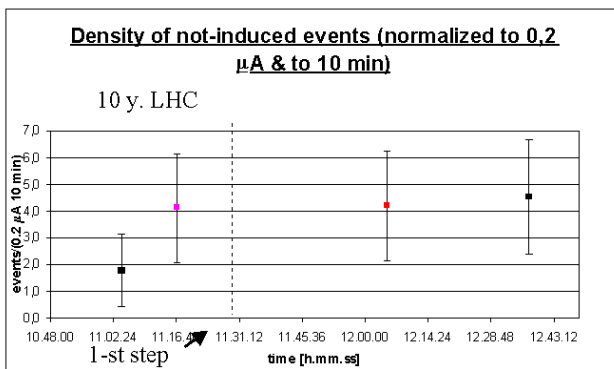


Figure 6: Time distribution of SEU events normalized to 0.2 μA beam current and integrated over 10 min data taking

In Figure 6 the distribution in time of such events is shown. Since during the run we have used slightly different primary beam currents in different irradiation steps and the SEU occurrence showed up to be linearly dependent on the flux, the numbers have been normalized to the current value of 0.2 μA we used in the first step. Moreover the time binning is set to 10 minutes. Missing bins correspond to running phases where some load variations were induced by the TTF operator.

In order to be more confident on the SEU origin of such effect we have repeated the same acquisition procedure at Torino INFN laboratory outside radiation and kept running for more than 24 hours continuously: no events of this kind was recorded.

Such instabilities should not be a problem for the operation of the CMS Tracker front-end electronics although the study is still in progress.

During the second irradiation step also the SASY control board reached the 10 years LHC equivalent neutron flux. We observed two kinds of SEU related effects: “Soft” events where the micro-controller hit by a neutron sends a reset command to the power supply board, setting all channels to zero volts, but still communicates with the remote SY2527 main controller, and “Hard” events where there is a loss of communication, signalled by an unplug status flag on the SY2527. To restore the communication with the SASY the system had to go through a complete “refresh” procedure. One soft and one hard events have been observed in the 10 years LHC limit. Being the CMS Tracker power supply system composed of more than 2000 units, with one micro-controller each and assuming 200 running days per year, this SEU rate translates into one Soft and one Hard events per day in the running experiment.

III. MAGNETIC FIELD TEST

The same SASY unit underwent a complete magnetic tolerance test on July 2-nd, at CERN-Preveessin area using the magnet shown in Figure 7



Figure 7: The NA20 magnet at the H8 line-Atlas test area

At this facility the field can be varied from 30 Gauss up to 15600 Gauss in fine steps of 3 Gauss. For our purpose the range between 0 and 2000 Gauss was explored. Its linearity was accurately checked before and found to be appropriate for our purpose.

The experimental setup used for the measurement was essentially the one depicted in Figure 2 with the addition of current probes on the power lines in order to be able to extract the SASY power efficiency. The magnetic field orientation was set in order to reproduce the worst case operation for the power supply transformers.

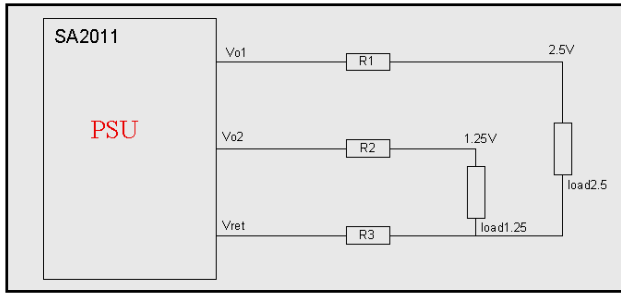


Figure 8: Schematic view of the SA2011 low voltage outputs load connection. R1,R2,R3 represent the line impedances.

Figure 8 shows schematically the connection of the low voltage outputs. The high voltage lines power absorption is very marginal compared to the low voltage one, so it has been neglected. The line impedances have been measured on site and their values are: $R1=0.149\Omega$, $R2=0.228\Omega$, $R3=0.059\Omega$.

The power efficiency of the SA2011 board alone is simply defined as $\varepsilon = P_{out}/P_{in}$ and is plotted in Figure 9 as a function of the output power and in Figure 10 as a function of the external magnetic field. The curves correspond to an interpolation of experimental data. Crate auxiliaries and control board dissipate a fix amount of power that have been measured to be 25 W and is not included in these plots.

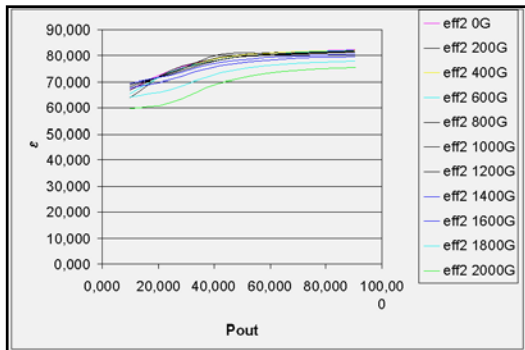


Figure 9: The SA2011 board efficiency vs. the output power. Different lines correspond to different values of the magnetic field.

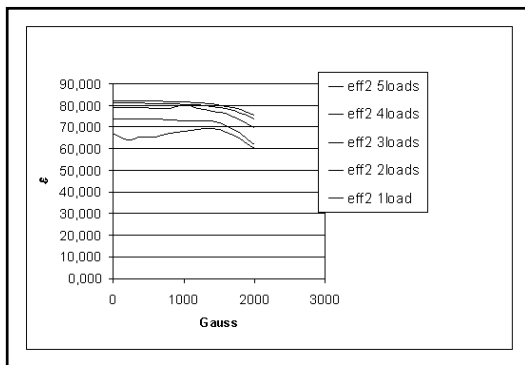


Figure 10: The SA2011 board efficiency vs. the external magnetic field. Different lines correspond to different loads

It can be seen that the efficiency is always very good with values of the order of 75% and that the external magnetic field has marginal effects on the performance of the power supply. As mentioned previously the magnetic field foreseen in the underground area is about 400 Gauss. A slight reduction in the efficiency is visible only above 1200 Gauss.

Another aspect that was investigated was the functionality of the crowbar circuit at different values of the external field. The crowbar circuit limits the response of the power supply to a sudden reduction of resistive load. Having fixed a certain load transition we checked the over voltage behaviour varying the B field between 0 and 2000 Gauss. No visible effect was observed.

IV. CONCLUSIONS

The SA2011 board, developed by CAEN for the CMS Tracker detector, has been extensively tested both in radiation using the T2 neutron beam line at Louvain-la-Neuve and under magnetic field at CERN-Preveessin in order to study the tolerance of the power supply to the working conditions expected in the CMS underground area. The SASY has to be considered a functional board more than a real prototype, but the interest stays in the technology and in the components choice adopted by CAEN that will be also implemented in next generation power supplies, namely the EASY ones. The measurements here presented have been obtained using a dedicated test equipment developed at Torino INFN laboratory: in particular a programmable test fixture that allows to simulate the CMS Tracker detector power absorption and its dynamics and a fast digitizer to monitor the DC output lines stability.

For an integrated flux of 1.2×10^{11} n/cm², evidence for three types of SEU events have been recorded: instabilities (9 events) on the 1.25V output line with amplitude up to 290mV, 1 sudden reset of the output voltages without loss of communication with the main controller (Soft event) and 1 loss of communication between the SY2527 and the SA2011 (Hard event).

The SASY has also been extensively tested after irradiation and its characteristics have shown to be compatible with pre-rad tests and still matching the project electrical specifications. Nevertheless the SEU effect during the irradiation cannot be considered negligible and further tests are being planned to quantify more precisely the expected MTBF of a system composed by 2000 PSU.

Concerning the magnetic field tolerance, CAEN technology has proved to be very robust and no problems have been observed up to 2000 Gauss.

We would like to acknowledge P. Sharp for his encouragement and his advice, F. Faccio and M. Huhtinen for useful discussions on SEU physics, E. Forton for his collaboration at UCL. A special acknowledge goes to G.Parrini and R. D'Alessandro for their support during the definition of the acquisition system and for the interest they have demonstrated in all the phases of the work.

V. REFERENCES

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