

RCU2 testing and design

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Master Thesis

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3 Introduction

4 Testing at Oslo Cyclotron Laboratory(OCL)

4.1 About OCL

Oslo cyclotron Laboratory is located at the Department of physics at the University of Oslo, and was opened in 1978. The cyclotron is of the type MC-35 and was made by Scanditronix AB from Sweden. This is the only accelerator in Norway for ionized atoms used in basic research. The cyclotron can accelerate protons, Deuteron, 3He and 4He , with energies and intensities as seen in the table 1 bellow. A drawing of the lab can be seen bellow in figure 1. The laboratory is divided in tree the control room, the inner experimental hall and the outer experimental hall. The cyclotron is placed in the inner hall, and a beam is sent through pipes to the outer hall. There is vacuum inside the cyclotron and the pipes that leads to the test area so that you should not suffer energy loss from collision with air molecules. With magnet you are able to regulate the beam, so that you are able to get the beam to your desired pipe exit. There are also several cups put on the pipeline, that you are able to block the beam. These can be used to stop the beam during an experiment, so you are able to go into the experimental area and do changes on your setup. When the cyclotron is running and the beam is on, you are not allowed to enter the inner experimental area.

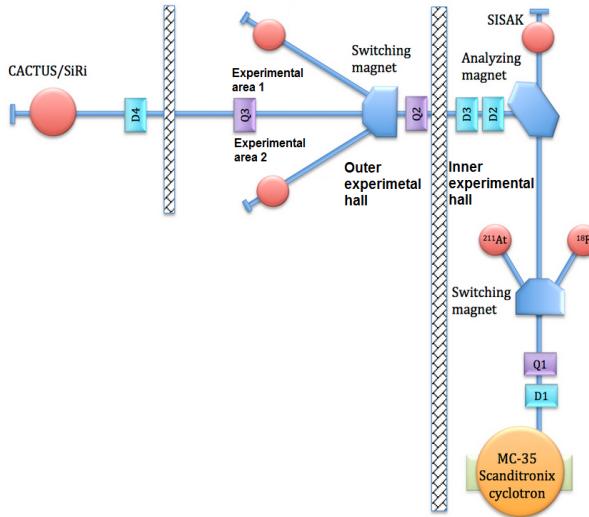


Figure 1: Out-lay of the OCL

Ionized beam particle type	Energy(MeV)	Intensity(μ A)
Proton	2-35	100
Deuteron	4-18	100
3He	6-47	50
4He	8-35	50

Table 1: Ionized beam particle data table

4.2 Experiment setup and equipment

The experiment setup was placed in the outer experimental hall in "experimental area 2". The setup that was used as well as the equipment used can be found in the figure and table bellow: The equipment was kept in close to the same height around 140-150cm. Beam exit was in a height of 141.5cm.

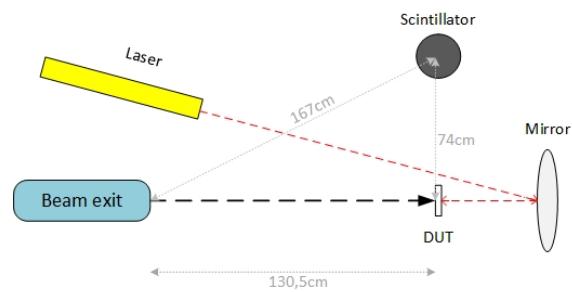


Figure 2: Experimental setup seen from above

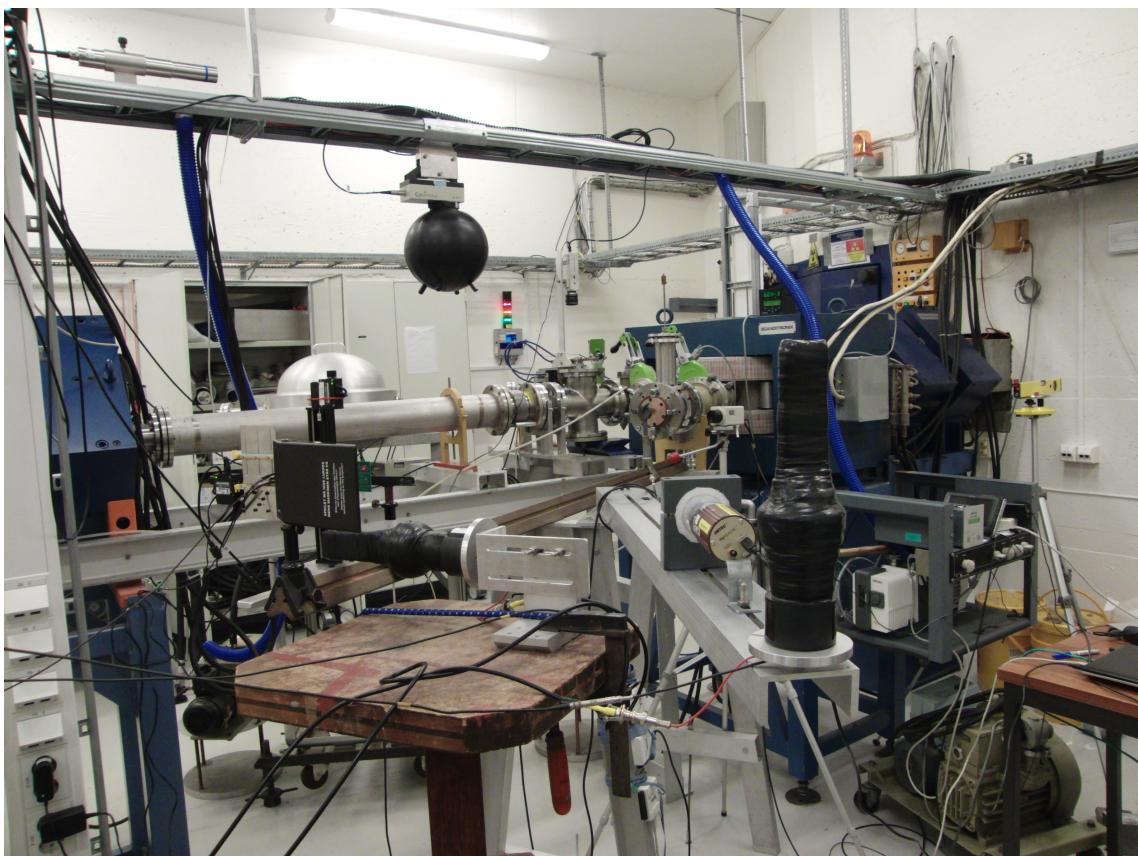


Figure 3: Picture of the experimental area

Equipment	Explanation
Scintillator	A plastic scintillator with photomultiplier, that was used to measure relative radiation. We had two of these, one that was placed right under DUT and one that was placed 75cm away from DUT. We only used one during the experiment.
High voltage regulator	Voltage for the photomultiplier. 800V was used
8 test boards	TPS51200, MIC69302WU, SN74AVCB16245, SN74AVC2T245, QS3VH257, SY89831U, ADN2814 and MAX3748
SRAM-board	A PCB board with 4 SRAM cells, that was used to characterise the beam and to measure scintillator counts
Computer	A VPN connection was set on a computer inside the experimental hall, so we were able to control the experiment outside the experimental hall. The computer was running LabView to control the experiment, data was also saved on the computer
USB DAQ	Used to get analog and digital connection to the test boards and send data to the computer.
Radiation film	A film that reacts when radiated with protons. Used to identify the beam.
Counting controller	a device that counts rising or falling edges
leveled laser	This was used to pinpoint the center of the beam.
Mirror	Reflecting the laser beam to the backside of the test boards.
XY-controller	Connected to the computer so we can do minor changes to the placement of the test boards outside the experimental area

Table 2: Equipment used in the experiment

4.3 Measurement equipment and test boards

4.3.1 SRAM

The SRAM board consist of several SRAM chips and a flash based FPGA and some connections and supporting electronics. When a SRAM chip is exposed to radiation a Single Event Upset(SEU) can occur. The method of detecting an Single Event Upset (SEU) in a SRAM is rather straight forward, as can be seen in the flow diagram of figure 4. There is an initial startup phase where a known pattern is written to all the addresses in the SRAM. When the startup phase is done, the value from the first address is read back and compared to a known value by xoring the known value with the read. If they are not alike a SEU has occurred, and a 1

will return from the xor and be added to a SEU counter. The correct value is then written back to the address and the system moves on to the next address.

A checkerboard pattern, a pattern of alternating ones and zeros, is used when writing to the SRAM. To check for stuck bits, the bit pattern in the whole address space is inverted after each read. The cross section for SEU and particles is known through earlier experiment with the SRAM-board, and is found to be $1.14 \times 10^{-6} \text{ cm}^2$. The FPGA on the SRAM PCB is designed with RS485 two-way communication which makes it possible to edit firmware as well as sending data out. Through the experiment the SRAM PCB was connected with RS485 to a ‘en box som arild hadde’ that could be connected to a computer. On the computer we run a LabVIEW program, that made us able to monitor data, as well as doing some settings. The SRAM board also had an input for scintillator counts, so we could monitor scintillator counts by the use of this board.

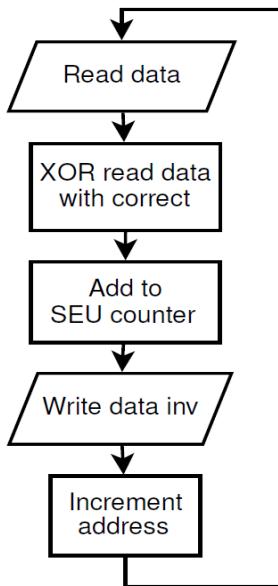


Figure 4: Flowchart for SEU detection

4.3.2 Scintillator

The detection of ionizing radiation by the scintillation light produced in certain materials is one of the oldest techniques on record. In Geiger and Marsdens famous scattering experiment of α -particles off Gold nuclei, the scattered as were observed via the scintillation light they produced when they hit a ZnS-screen. ZnS produced light flashes, called scintillation light, when hit by an α . The scintillation process remains one of the most useful methods available for the detection and spectroscopy of a wide assortment of radiation.

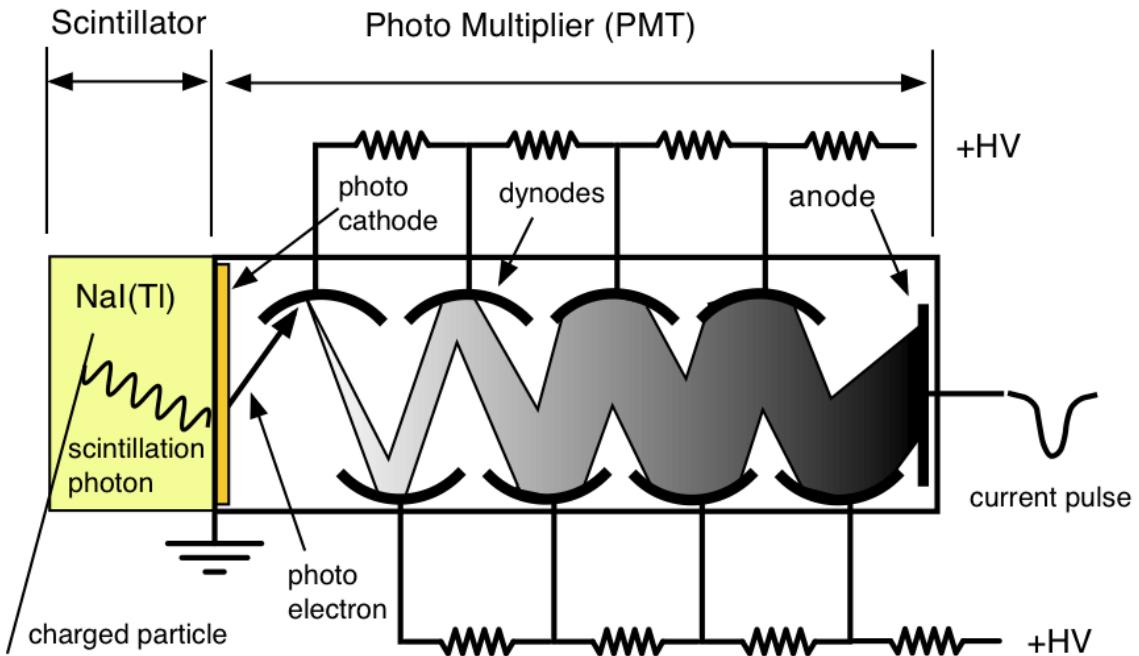


Figure 5: Concept drawing of scintillator

4.3.3 The test boards

TPS51200 - A Sink/Source DDR termination regulator. Used to power DDR RAMs. We are going to use this for 0.75V DDR3 RAM.

MIC69302WU - This is a high current low voltage regulator. Is going to be used to produce a 1.2V voltage.

SN74AVCB16245 - This is a 16-bit noninverting bus transceiver, with configurable voltage transceiver and 3-state outputs.

SN74AVC2T245 - This is a dual-bit noninverting bus transceiver ,with configurable voltage transceiver and 3-state outputs

QS3VH257 - This is a Quad 2:1 multiplexer/demultiplexer with high bandwidth bus switch

SY89831U - This is a high speed, 2GHz differential LVPECL 1:4 fanout buffer optimized for ultra-low skew applications

ADN2814 - This is a clock and data recovery IC with integrated Limiting amplifier. works in rate of 10Mb/s to 675 Mb/s. Is going to be used to give out LVDS signal of a optic Manchester signal.

MAX3748 - This is a limiting amplifier. works in rate of 155Mb/s to 4.25Gb/s. Is going to be used to give out LVDS signal of a optic Manchester signal.

4.4 Preparation and characterization of the beam

Before we could start testing the test boards, the cyclotron had to be made ready for a proton beam and the magnet controlling the direction had to be put in the right position to get the beam out in experiment area 2. This was done by the experienced lab personnel.

4.4.1 purpose of tests

The purpose of testing these board is to see if they are able to survive in a highly radiated area. Every IC that has been tested, are IC's that are going to be used in creation of the new RCU2 board, that is going to be placed in ALICE at CERN.

4.4.2 Beam setup

When the beam was set, we could start the characterization of the beam. The first thing to do is to get an understanding of the beam, too see that it is centered and that it hits around the area that we expect. This was done by using radiation films that turns black when exposed to radiation. We put one of these right in front of the beam exit and one in front of DUT-area to see how the beam looks like at the two places. This gave us a hunch of where the beam goes. A more precise calibration was done by the use of the SRAM board and the scintillator. By measuring the relation between scintillator counts on the scintillator which was in a locked position and SEU on the SRAM that was connected to a XY-controller(which made the SRAM freely to move), we were able to find a more precise position of the beam center by seeing which position gives most SEU compared to scintillator counts.

This had to be done everyday at startup before we could start the tests. When the beam center is found and everything looks fine, the laser was placed in a position so the laser points to where we have found the center of the beam to be. After that we could switch out the SRAM board with the PCB that we were going to test. We were able to control the intensity of the beam freely from the control room inside the limitation of the beam (for protons that is up to $100\mu\text{A}$). This way we could control the dose of radiation we were giving to the test boards. The beam intensity could be measured with a Faraday Cup(FC), by putting it in front of the beam. But the FC had to be removed when we were doing tests, since it will block the beam.

4.4.3 The test procedure

Before the test day I had made simple test program in LabVIEW for each PCB that we were going to test. Each PCB had a mark on the back indicating the center of the IC. The PCB picked out for testing was placed in so that the laser pinpoint this mark, then the IC should be in the center of the beam. We were running 3 labVIEW programs through the experiment, one for controlling the XY-controller, one for SRAM PCB(for scintillator counts) and one program for each of the test boards. The SRAM and test board programs were constantly saving data on the disk.

5 Results and calculations from beam test at OCL

The radiation was done in 5 days divided in two periods 13.11-15.11 and 28.11-29.11. I have made two version of most of the boards, the exception is ADN2814 and MAX3748 which I only made one version of. The boards that where tested the first time are $TPS51200_1$, $MIC69302WU_1$, $SN74AVCB16245_1$, $SN74AVC2T245_1$, $QS3VH257_1$ and $SY89831U_1$ tested in that order. The first time at OCL we where given an beam of 28MeV, but the second time, the lab personnel manage only to produce a beam of 25MeV. When the beam gets out through the beam exit the energy will be reduced by crashing with air particles(21keV per cm), so at DUT area the beam was approx 25MeV and 22MeV.

5.1 Calibration process

As explained in chapter 4.4.2, we had to start with finding the center of the beam. In table 3 you can see the results from our calibration 15.11.2013. We see that position $x = -2,5$ and $y = -1$ gives highest relation between SEU on the SRAM and SC. We run a total of 4 tests in that position and the average value gives us 0,0948. This value was used to calculate from SC to SEU, since there is a known cros section(CS) from SEU to fluence. The CS is given in equation 2.

$$scint_{conv} = SEU(SRAM) * SC = 0,0948 \quad (1)$$

$$CS = 1,14e - 6 \quad (2)$$

Calibration test nr.:	x	y	Scint rel	SEU(SRAM)	SEU(SRAM)/SC
1	-0,8	-1	27798	1463	5,26E-02
2	-1,3	-1	17721	1239	6,99E-02
3	-1,8	-1	12904	1203	9,32E-02
4	-2,3	-1	13361	1276	9,55E-02
5	-2,8	-1	12786	1238	9,68E-02
6	-3,3	-1	12342	1156	9,37E-02
7	-2,5	-1	11696	1223	1,05E-01
8	-2,5	-1,5	11027	1075	9,75E-02
9	-2,5	-2	11835	1063	8,98E-02
10	-2,5	-0,5	15593	1540	9,88E-02
11	-2,5	0	12620	1034	8,19E-02
12	-2,5	-1	65280	5999	9,19E-02
13	-2,5	-1	52752	4803	9,10E-02
14	-2,5	-1	57229	5250	9,17E-02

Table 3: Calibration tests 15.11.2013

5.2 Calculation of dose

After a beam test had been run, we knew the exposed time and scintillator counts(SC). From the calibration we knew the relation between scintillator counts and SEU on the SRAM, and cross section(CS)(the probability that an incoming particle will induce an SEU) of the SRAM is also known. We start by calculating SEU from the factor given in equation 1. Then we calculate the fluence at DUT as seen in equation 3, and by this we can calculate the flux, see equation 4. To calculate the dose from here we need to know some more factors. We run a simulation on a program called FLUKA. This program is used to simulate particles in different environment. We simulated a proton beam of 28MeV and 25MeV, and inserted the distance from BE. We where given the results as seen in table 4. Then we had enough information to calculate the dose. As seen from equation 5 we are able to find the Fluence at BE. And from there we can calculate the the dose at DUT, see equation 6.

Fluka simulation results 28MeV	
Dose/primary particle at DUT[Gy]	4,08E-10
Primary particles at Beam exit	1
Primary particles at DUT	0,1331
Beam intensity reduction at DUT	7,513148009

Table 4: FLUKA simulation with 28MeV proton beam

$$Fluence_{DUT} = \frac{SEU}{CS} \quad (3)$$

$$Flux = \frac{Fluence}{time} \quad (4)$$

$$FluenceBE = \frac{fluence_{DUT}}{primary_{p}articles_{DUT}} \quad (5)$$

$$Dose_{DUT}[Gy] = FluenceBE * \frac{Dose}{primary_{p}articleat_{DUT}} \quad (6)$$

$$1Rad = 100Gy \quad (7)$$

5.3 test results

The tests was controlled and monitored through a LabVIEW program for each of the different IC. ADN2814 and MAX3748 there was also needed a SF2 board, to configure and monitor the input signal. A complete result of the tests can be found in one of the appendix. The point of this test was to see that these IC's would survive in a radiated area, as where they are supposed to be used at CERN. In table 5 and 6 you can see how long each IC has been exposed, the dose they has been received and if an error occurred.

Bellow in figure 6 and 7you can see graphs of flux vs time for the different test boards. The reason for that graph don't go as linear, is that the beam sometimes fell out and that we increased the intensities when we saw that thing went a little slow.

Device	Exposed time[s]	Dose[Rad]	Error
<i>TPS51200</i>	2065	41800	No
<i>MIC69302WU₁</i>	2240	164000	No
<i>SN74AVCB16245₁</i>	967	65200	No
<i>SN74AVC2T245₁</i>	860	4600	Yes
<i>QS3VH257₁</i>	795	52800	No
<i>SY89831₁</i>	1251	93500	No

Table 5: Tests at OCL 15.nov 2013

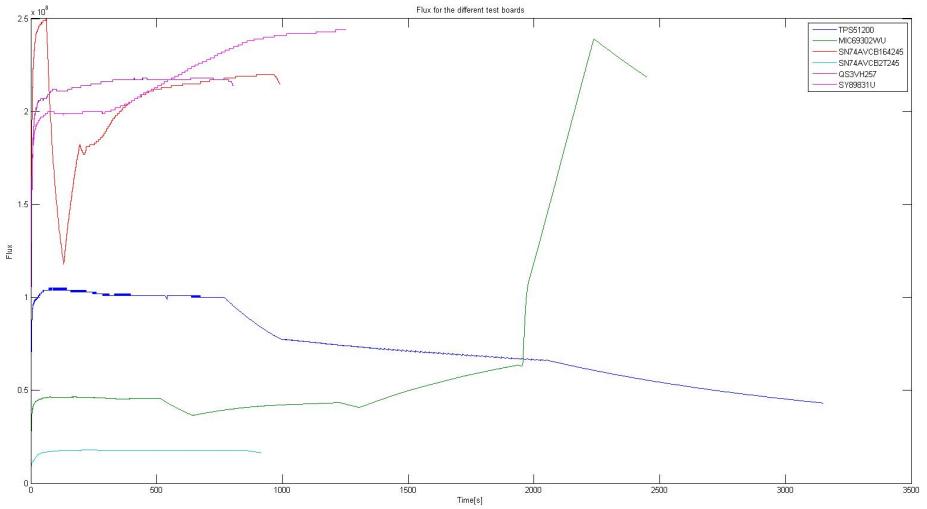


Figure 6: flux for each component radiated 15.11.2013

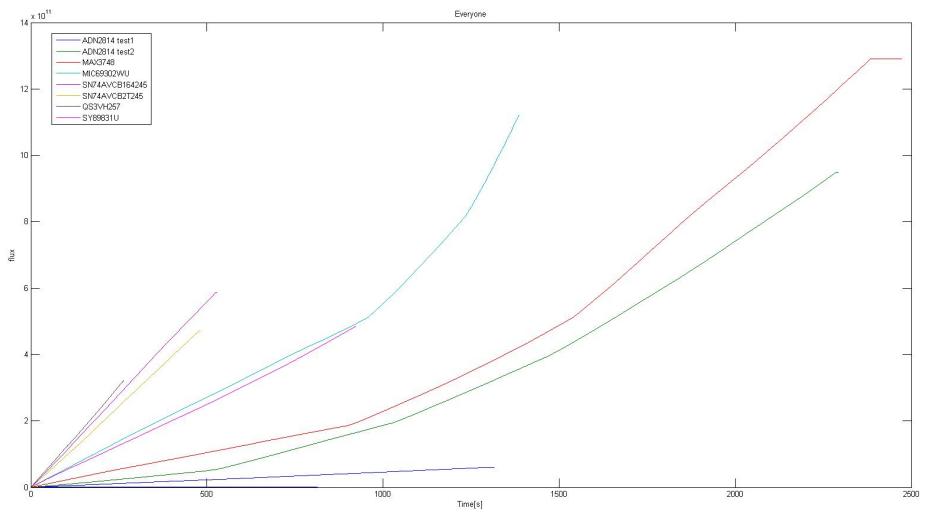


Figure 7: flux for each component radiated 15.11.2013

Device	Exposed time[s]	Dose[Rad]	
<i>ADN2814/run1</i>	1273	20200	Yes
<i>ADN2814/run2</i>	2286	324900	Yes
<i>MAX3748</i>	2384	442200	No
<i>TPS51200</i> ₂	-*	-*	-*
<i>MIC69302WU</i> ₂	1385	383800	No
<i>SN74AVCB16245</i> ₂	526	201400	No
<i>SN74AVC2T245</i> ₂	478	161600	No
<i>QS3VH257</i> ₂	264	110300	No
<i>SY89831U</i> ₂	921	165800	No

* The board wouldn't work at test time

Table 6: Tests at OCL 27-28.nov 2013

5.3.1 TPS51200

This was the first board that was tested. To measure the current going into the board, we added a 220Ohm resistor on the input, and measured over this resistor to calculate the current. A 3v3 voltage was supplied from the DAQs analog outputs. The output voltage was also monitored, through a analog input on the DAQ-box. The intensity was a little low on this test. To make the testing process faster the intensity was increased during the next test. The IC worked after a dose of 40kRad, but we could see a little increase in current after a dose of 25kRad. The output voltage is close to stable, a few mV up and down, but not noteworthy. Two circuit of this type was tested, but only one worked when we was at OCL, when we was going to test.

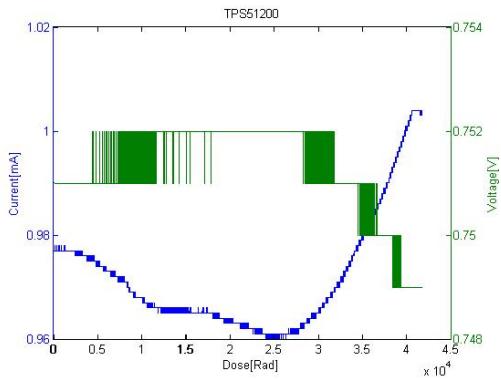


Figure 8: TPS51200 - Current/Voltage vs Dose

5.3.2 MIC69302WU

The first board was tested 15.11.13 and the second board was tested 28.11.13. During the test of the first board we increased the intensity of the beam quite allot, that

can be seen from the flux graph, figure 6. The current was measured, by adding a 220Ohm resistor on the input, and measure the voltage over the resistor to calculate the current. This chip had an unexpected reaction to radiation. You can see from both of the graphs that the current is decreasing and voltage is increasing, normally we would expect the opposite, or at least that the current would increase. It starts quite early to decrease in current, but as you can see it also stabilizes after a while. The output voltage is mostly stable, there were an increase of 2% on both the tests.

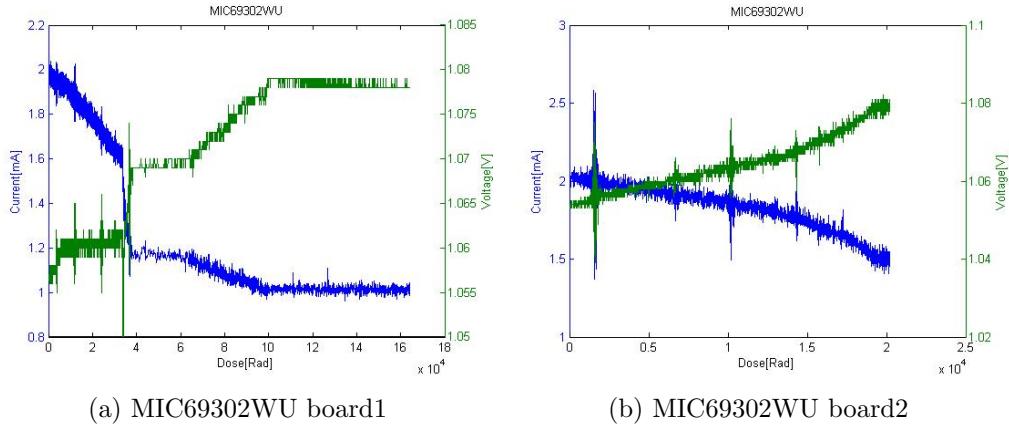


Figure 9: MIC69302WU - Current/Voltage vs Dose

5.3.3 SN74AVCB16245

It can be seen that the characteristics on the two test boards are different, the reason for this is maybe because of different output load. The reason for the “jumps” in current is because the output is constantly changing from on to off, with a gap of 4 seconds. This chip is not effected by radiation before a dose of approx 40kRad. That is more than enough for the purposes we are going to use this for. The current was measured in the same way as the two previously circuits, a 220Ohm resistor was placed in series with power supply, and voltage over the resistor was measured and used to calculate current. To make sure that the circuit didn’t drag current through the input on the chip, we used a pMOS transistor, that was connected to supply pin on Drain, to ground on Source and Gate to a digital output from the DAQ. That way the current has to come from the power supply input, and not from the digital output of the DAQ. The outputs were measured by digital inputs.

5.3.4 SN74AVC2T245

This chip is almost the same as the SN74AVCB16245. A 220Ohm resistor was used at the input to measure current, and a digital output from the DAQ was used to put the input high and low. Something went wrong on the first test. After 740s and a dose of 98Rad the chip’s output was stuck at 1. The reason for this is unknown,

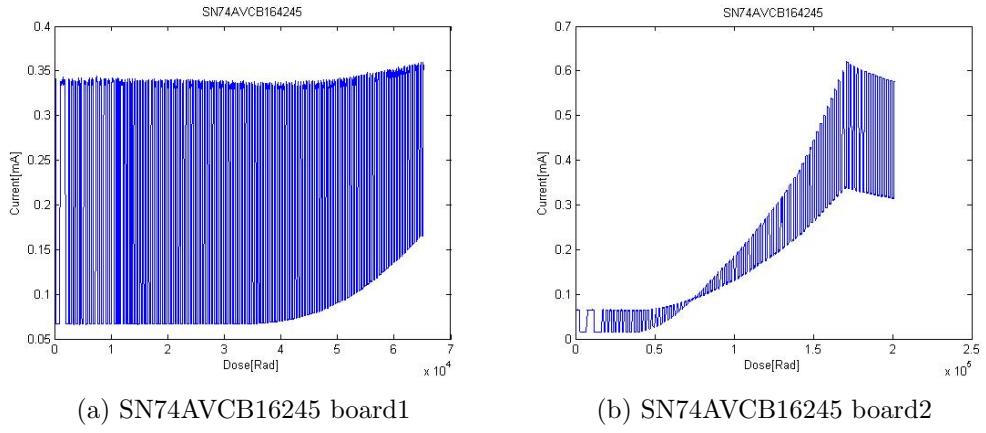


Figure 10: SN74AVC2T245 - Current vs Dose

I fear that this might be defected before we started the test, since it gives a totally different characteristics than test board nr2. The input was switching from high to low every 4 second. If we look at the test results from board 2. the current goes unchanged up to 40kRad, and that is more than enough.

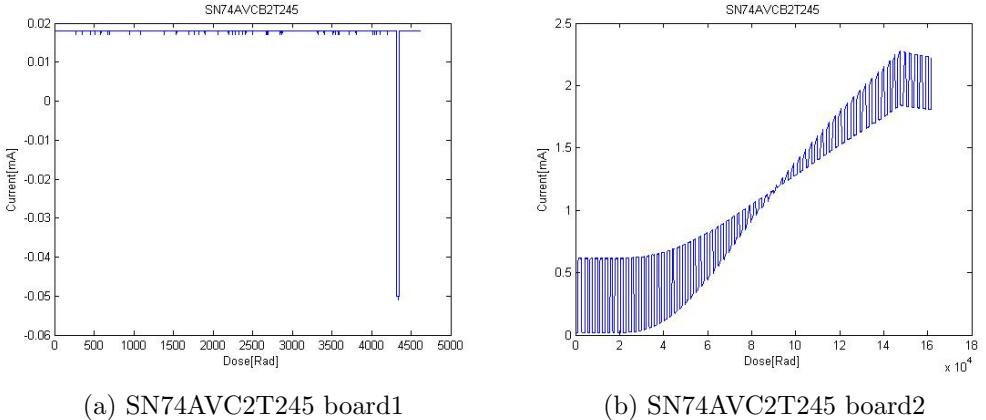


Figure 11: SN74AVC2T245 - Current vs Dose

5.3.5 QS3VH257

This was also tested by putting a 220Ohm resistor in series with the power supply, in the way explained earlier. For the Select input a analog output signal from the DAQ was used. The input signals was set by digital outputs from the DAQ. The outputs was measured by digital inputs on the DAQ. Both of the boards worked fine through the tests. Here the select input was changed every 4 second and the inputs was changed every 18second. We see that we have small increase in current before 30kRad, after that it increases quite allot. We couldn't see any errors on the output during the experiment, but it should probably not be exposed to more than 30kRad.

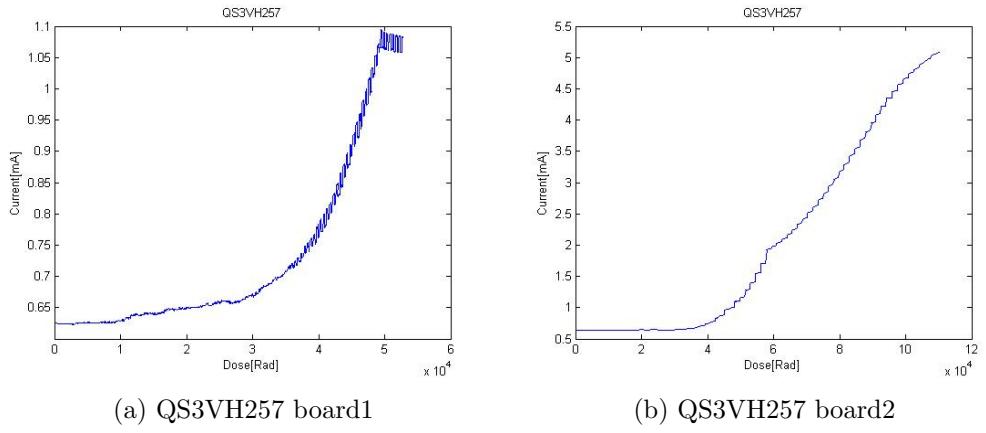


Figure 12: QS3VH257 - Current vs Dose

5.3.6 SY89831

This is a buffer used to make 1 clock to 4 clocks. This chip required a high current to work, and since the labVIEW DAQ box only delivers 5mA on the analog outputs, I had to use the 5V output on the DAQ that could deliver up to 200mA. But I also needed to have a 3v3 power supply, this was solved by using a modified MIC69302WU chip to supply this IC. To measure the current, I had to use 20hm resistor to make sure that I didn't had a voltage drop, because of the high current consumption.voltage over this 20Ohm was measured to get current. To test that the chip worked as it should, two analog outputs from the DAQ was used to make a DC differential input. This was measured by digital inputs on a DAQ to see that i goes high and low according to the input.

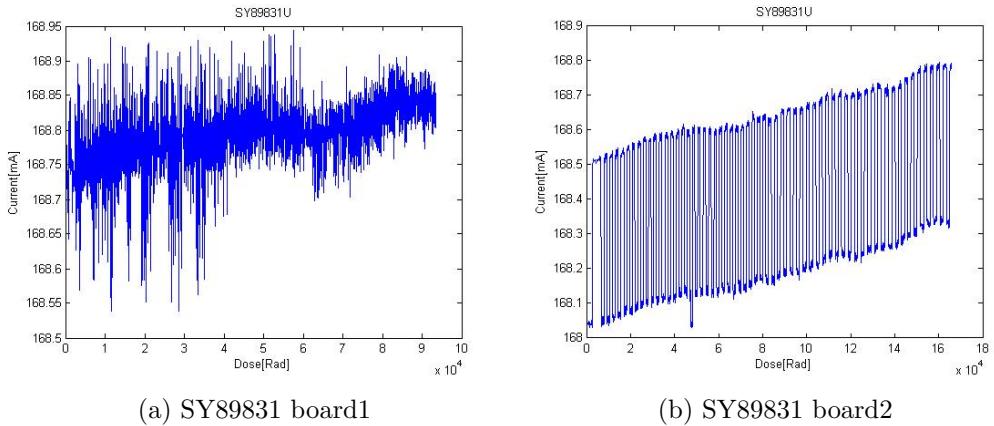


Figure 13: SY89831 - Current vs Dose

5.3.7 ADN2814

This IC is a little special and was hard to get a good test on. This is a clock and data return circuit, with a limiting amplifier. The SF2 board was used to code a clock and data into a differential Manchester signal, that was sent into the IC. Out of the IC we get a clock and a limited Manchester coded data signal. The Manchester coded data signal was decoded on the Igloo FPGA on SF2 board, so that we get out a clock and data. The data was tested by delaying the original data through a few D-latches, so that the original and returned data was close to alike. Then we could compare the original data with the one from the chip through a XOR-function, to see if they were alike. This function was triggered by a 80Mhz clock from the SF2 board. If they are not alike when the clock rises, the a 1 was added to a counter, and sent through the UART. The way the clock was tested was a little harder process since the clock was so fast(160Mhz). The way this was solved, was by adding a third clock that was 90° of from the two others, when this goes high I called on the XOR-function, to see if the two other clocks are the same. If they are alike, nothing happens, if they are not the program adds 1 to a counter, which constantly writes its current value to a UART. The problem here is that for each time the SF2 board was programmed the clock was slightly different, that made either the clock or sync or the data of sync, so that the code didn't work as it should. This circuit also requires allot of current, therefor the same solution as for SY89831 was used, using MIC69302WU as a power supply and measure the current on the Micrell chip. The current didn't change before a dose of 200kRad had been received, but we got a clock error at a dose of 11kRad, and a data error after a dose of 8kRad. How good this test really is, could be discussed, since we don't have any data on the clock and data, other than that it the XOR-function failed, what really failed, and how much is impossible to know. It could be a slight delay on a clock or the data, or maybe the clock just disappeared for a moment. There could also be a problem with the clocks on the SF2 board.

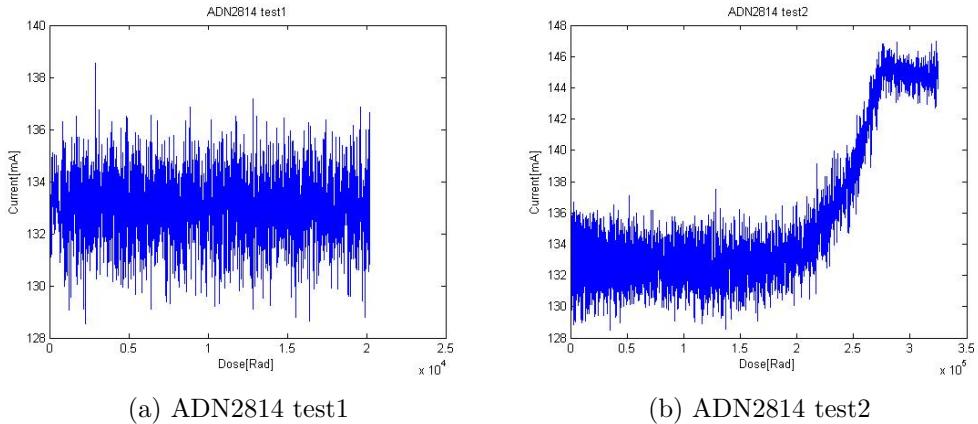


Figure 14: ADN2814 - Current vs Dose

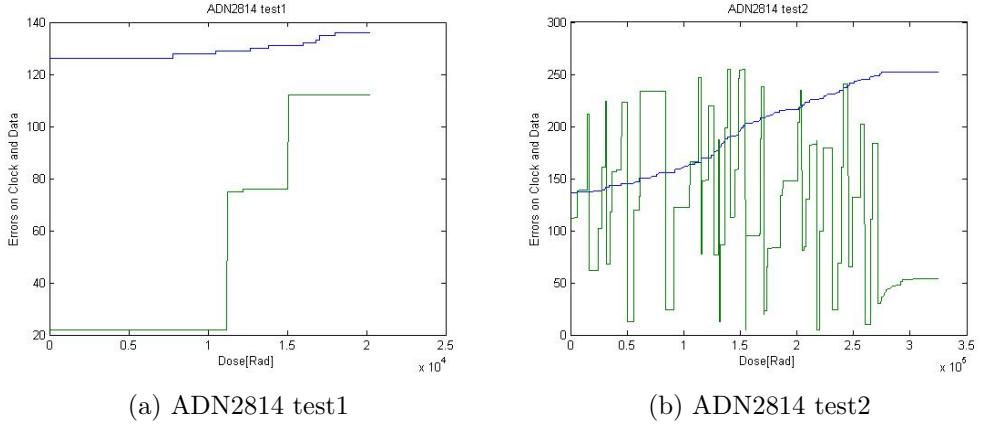


Figure 15: ADN2814 - Relative errors vs Dose

5.3.8 MAX3748

This circuit has the same purpose as ADN2814, but this is only return limited Manchester coded signal. The data was decoded on the SF2 board, by the use of the igloo FPGA, that gives out the original data and clock. The decoding process return clock and data, but since they are related to each other, a error on the clock would mean an error at the data. So by measuring data, we can be sure that there are no clock errors as well. The process for testing if the data into the chip was the same as the data coming out, was the same as for the ADN2814 circuit.

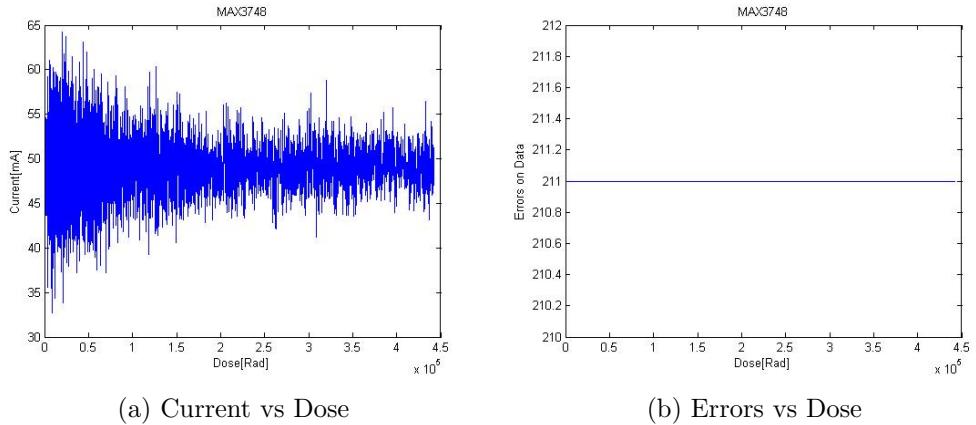


Figure 16: MAX3748

The total dose of 10 years in ALICE-experiment is estimated to be 0.6kRad. If a IC survives more than 10 times that, we can be quite sure that it will survive the radiation it will receive at CERN.

Calibration test nr.:	x	y	Scint rel	SEU(SRAM)	SEU(SRAM)/SC
1	0	0	23813	1971	8,28E-02
2	0	-0,5	37930	3867	1,02E-01
3	0	-1	27527	2817	1,02E-01
4	0	-1,5	34413	3360	9,76E-02
5	0	-2	32713	2763	8,45E-02
6	0,5	0	38753	2709	6,99E-02
7	-0,5	0	23420	2483	1,06E-01
8	-1	0	20611	2232	1,08E-01
9	-1,5	0	21014	2410	1,15E-01
10	-1,5	0	20676	2260	1,09E-01
11	-2	0	35787	3776	1,06E-01
12	-2,5	0	27847	2512	9,02E-02

Table 7: Calibration tests 14.11.2013

6 Appendix

Calibration test nr.:	x	y	Scint rel	SEU(SRAM)	SEU(SRAM)/SC
1	-0,8	-1	27798	1463	5,26E-02
2	-1,3	-1	17721	1239	6,99E-02
3	-1,8	-1	12904	1203	9,32E-02
4	-2,3	-1	13361	1276	9,55E-02
5	-2,8	-1	12786	1238	9,68E-02
6	-3,3	-1	12342	1156	9,37E-02
7	-2,5	-1	11696	1223	1,05E-01
8	-2,5	-1,5	11027	1075	9,75E-02
9	-2,5	-2	11835	1063	8,98E-02
10	-2,5	-0,5	15593	1540	9,88E-02
11	-2,5	0	12620	1034	8,19E-02
12	-2,5	-1	65280	5999	9,19E-02
13	-2,5	-1	52752	4803	9,10E-02
14	-2,5	-1	57229	5250	9,17E-02

Table 8: Calibration tests 15.11.2013

Fluka simulation results 28MeV	
Dose/primary particle at DUT[Gy]	4,08E-10
Primary particles at Beam exit	1
Primary particles at DUT	0,1331
Beam intensity reduction at DUT	7,513148009

Table 9: FLUKA simulation with 28MeV proton beam

Fluka simulation results 25MeV	
<i>Dose primary particle at DUT</i> [Gy]	2,94E-10
Primary particles at Beam exit	1
Primary particles at DUT	8,57E-02
Beam intensity reduction at DUT	11,6713352

Table 10: FLUKA simulation with 25MeV proton beam