Single Event Upset Studies for the ATLAS SCT and Pixel Optical Links

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Abstract

Optical data transmission has been chosen for the ATLAS Pixel and SemiConductor Tracker to deliver both timing and control information to the detector modules and transmit tracking data to the remote computer room. Radiation hardness of individuals optical components and their ASICs drivers have been reported in previous papers. We will report here the Single Event Upset studies carried out on a customised optopackage using a high-energy pion beam. It will be shown that the system is sufficiently robust to SEU at the ATLAS SCT level.

I. INTRODUCTION

Optical links will be used for the readout of the ATLAS SCT and Pixel detectors[1]. A dedicated radiation hard, low mass and non magnetic optopackage has been developed with VCSEL emitters and Epitaxial Si PIN photodiode receiver. Details of the design and its performance are described in [2] . The two on-detector ASICs have been designed in the AMS 0.8 µm BiCMOS process. Although it is not a radiation hard process, both the circuit and the layout have been designed to minimise the effects of radiation. Components expected to have good radiation tolerance have been chosen: npn bipolar transistors, polysilicon resistors and poly1-poly2 capacitors. Transistors were operated at high current densities where radiation effects were expected to have least effect on their characteristics. Finally, circuits were designed to be very tolerant to changes in absolute values of passive components and in particular in the value of transistor gains [3].

Although the radiation hardness of all the previous components has been established and shown to be suitable for the ATLAS SCT environment, Single Event Upset (SEU) is becoming a major concern with the radiation level achieved at LHC. This effect is caused by a particle depositing lots of energy in a small volume of an electronic component. The charge released along the ionising particle path is collected promptly, a current transient is produced which might generate an SEU. The most sensitive regions of a microelectronic device are the reverse-bias p/n junctions, where the high electric field is very effective in collecting the deposited charge by drift. Preliminary studies have shown that our system was insensitive to a Sr^{90} ionising source and a 9 MeV neutron beam (see [4]) at a flux larger than that expected at the SCT. We will report here SEU appearance with a pion/proton beam in the momentum range from 300-450 MeV/c. From these results, the cross section for producing an SEU was deduced. The resulting Bit Error Rate (BER) was estimated to within the SCT specification.

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II. LINKS SPECIFICATIONS

The SCT links transfer digital data from the SCT modules to the off-detector electronics (RODs) at a rate of 40 Mbits/s and use NRZ coding of the digital readout data, with provision to operate also at 80 Mb/s for potential use within the ATLAS pixel subsystem. Optical links are also used to transfer Timing, Trigger and Control (TTC) data from the RODs to the SCT modules. BiPhase Mark (BPM) encoding is used to send the control data for a module on the same fibre as the 40 MHz bunch crossing clock. In this scheme, a 20 MHz clock is sent and each extra transitions are used to encode “1”s in the data as illustrated schematically in Figure 1.

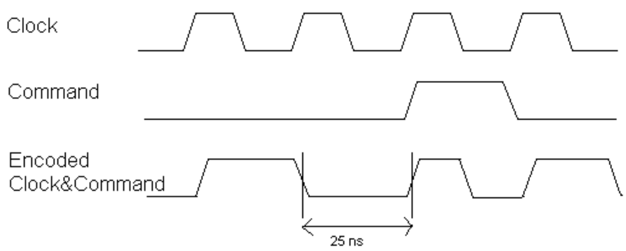

Figure 1 Bi-Phase mark encoding of TTC data.

The links are based on radiation-hard VCSELs transmitters and Si PIN photodiodes receivers. The VCSEL will be driven by a simple VCSEL Driver Chip (VDC) which translates LVDS data from the silicon module to the current signal used to drive the optical emitter. The PIN diode signal is received by the DORIC chip. The DORIC chip decodes the BPM encoded input data stream to recover the 40 MhZ clock and 40 Mb/s control data which are output in LVDS format.

Single Event Upset is most likely to take the form of spurious signal generation in the PIN photodiode which is decoded by DORIC as an erroneous data bit. DORIC and VDC themselves have been designed to minimise SEU effects by keeping the area of active components small. The epitaxial Si PIN, however, is 350 μm in diameter with an active thickness of 15 μm. The system specification is for a Bit Error Rate (BER) better than 10^{-9} s^{-1} which must be maintained at all times during the operation to avoid missing trigger information which would cause modules to lose synchronisation with the rest of the system. As the predominant particles in the SCT during operation will be pions with energies in the several hundred MeV range, a pion beam facility was chosen for the SEU study as described below.

III. EXPERIMENT

The pion beamline πM1 at the Paul Scherrer Institut (PSI), Villigen, CH, was used for the Single Event Upset study. It was possible to control the beam momentum in the range 300-465 MeV/c, thus enabling some measurement of the energy dependence of the measured SEU rates. The beams used consisted largely of positive pions (π^+), with less than ~20% proton contamination – the ratio depending upon the momentum used. The beam spot at the sample was measured to have FWHM of ~20mm in both transverse directions using a wire chamber. Fluxes were measured using a 2mm diameter disk of scintillator mounted in front of a photomultiplier tube, cross-checked using the activation of Al-foils. Both of the measurements agreed to within 10% which is within the independent measurement accuracy. Both ASICs were mounted on a kapton support structure similar to the final SCT style support along with a custom optical package containing two VCSELs and one epitaxial silicon PIN photodiode. This so-called “dogleg” was mounted in the beam as shown in figure 2. The beam spot were arranged to cover the area of both ASICs and the optoelectronics components. It can be assumed that the flux was uniform over this area of approximately $10mm \times 10mm$.

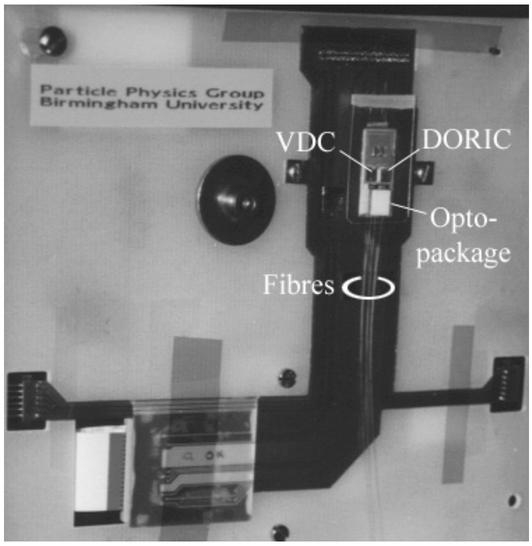

Figure 2: Devices mounted onto a “dogleg” for SEU testing at PSI. The beam passed through the center of the package and ASICs into the board.

A VME-based BER test system was used to measure the BER rate as a function of optical power. A reference data set was taken with no beam followed by data with the beam at various momenta.

IV. DATA RESULTS

Data were taken at PSI at four momenta and five particle fluxes as shown in Table 1. The BER is plotted as a function of the average photodiode current in Figure 3. There is a clear region where SEUs are observed at low optical input powers. Sufficient headroom is available in the system to allow larger optical signals to be used which swamp the signals produced by particles passing through the photodiode and recover the system BER to the specified level of $10^{-9}s^{-1}$. This is encouraging for the final application where the maximum flux in the SCT is not expected to exceed 3 10^6 cm^2 s^{-1}. At the SCT level, a BER which takes into account SEU could be estimated, as it will be shown in the next paragraph.

Table 1: Pion/proton fluxes obtained at different beam momenta in the PSI beam. The pion beam flux was measured with an accurancy better than ~10%, corrected for photomultiplier system dead-time.

Beam Momentum	Flux (cm^{-2} s^{-1})
300 MeV/c	2.95 10^6
350 MeV/c	5.71 10^7
405 MeV/c	4.96 10^6
405 MeV/c	1.16 10^8
465 MeV/c	1.22 10^8

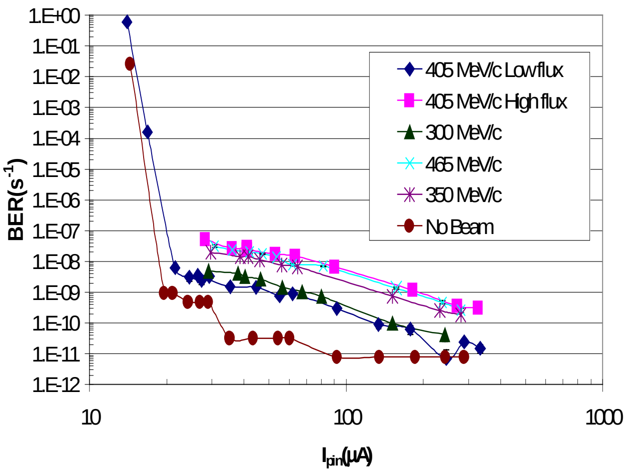

Figure 3: Measured Bit Error Rate before and during exposure to the PSI beam at various momenta.

An upset cross section (σ_{upset}) is calculated from the ratio of the number of errors N_{err} observed in a given interval to the fluence ϕ in the same time interval:

$$\sigma_{upset} = \frac{N_{err}}{\phi}$$

The measured σ_{upset} is shown in Figure 4. Data for high and low flux at a beam momentum of 405 MeV/c are in agreement indicating a linear scaling with flux and thus allowing these results to be used to scale to different rates that may be encountered in the final application in different regions of the detector. One possible explanation for the higher BER cross-section at 300 MeV/c is the Δ resonance in pion-nucleon scattering which gives rise to a marked increase in the total pion-proton interaction cross-section. Detailed Monte Carlo simulations would be needed to verify this.

We can scale the additional energy deposit from the passage of a high energy particle through the photodiode from a simple model of DORIC as an RC filter:

$$E_{\min} = 10^{-12} \times (I_{pin} + lh) \times \frac{E_{eh}}{e\omega_0}$$

where:

E_{min} minimum energy deposit required to trigger DORIC (MeV)

I_{pin} average photocurrent (μA)

lh constant representing the hysteresis in DORIC4A (10)

E_{eh} mean energy required to create an electron-hole pair in silicon (3.6 eV)

e elementary charge ($1.6x10^{-19}$ C)

$\omega_0 = \frac{1}{RC}$ (10^9 s^{-1}) time constant of the DORIC input stage

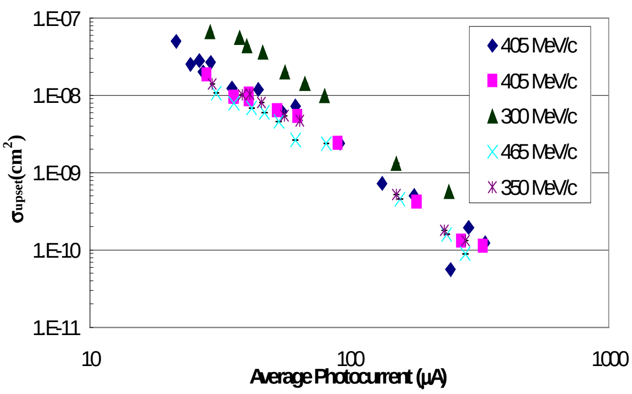

Figure 4:Measured SEU cross-section for the different beam momenta available at PSI.

The energy necessary to trigger a bit-flip in DORIC for a 30μA input photocurrent is of 0.6 MeV, up to 3.6 MeV at 100 μA.

V. Estimated BER with the SCT flux

Provision has been made in order to deliver at the system level an input power level of 1mW. The loss introduced by the patch panel, added to the loss due to the radiation damage in the fibre, could be estimated of 4 dB. The PIN photodiode responsivity, estimated to be 0.3 A/W after 10 years of irradiation, gives a minimal input current of 100μA. For such a value, the measured cross-section will be 6 10^{-9} cm^2. With a SCT flux of 3 10^6 n cm^2 s^{-1} and a data rate of 40 Mbit/s, we obtain an estimated BER of 6 10^{-10} (± 1.7 10^{-10}) s^{-1}, lower than the 10^{-9} SCT BER specification.

VI. CONCLUSIONS

On-detector components of the data links have been proven to be sufficiently radiation hard for use in the SCT. System testing in a pion beam of similar intensity to the flux levels expected in the SCT have shown that the data links can be operated in a regime where the effect of SEU can be minimised by choosing a sufficiently high input power level.

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