RADIATION RESISTANCE TESTING OF COMMERCIAL COMPONENTS FOR THE NEW SPS BEAM POSITION MEASUREMENT SYSTEM

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Abstract

A new Front-End (FE) electronics is under development for the SPS Multi Orbit POsition System (MOPOS). To cover the large dynamic range of beam intensities (70 dB) to be measured in the SPS, the beam position monitor signals are processed using logarithmic amplifiers. They are then digitized locally and transmitted via optical fibers over long distances (up to 1 km) to VME acquisition boards located in surface buildings. The FE board is designed to be located in the SPS tunnel, where it must withstand radiation doses of up to 100 Gy per year. Analogue components, such as Logarithmic Amplifiers (LA), ADC-Drivers (ADC-D) and Voltage Regulators (VR), have been tested at PSI (Paul Scherrer Institute) for radiation hardness, while several families of bidirectional SFP, both single-fiber and double-fiber, have been tested at both PSI and CNRAD. This paper gives a description of the overall system architecture and presents the results of the radiation hardness tests in detail.

INTRODUCTION

The SPS orbit and trajectory measurement system relies on 216 Beam Positions Monitors (BPM) distributed all around the machine. Most of the pick-ups are electrostatic rectangular "shoe-boxes", measuring either horizontal or vertical beam positions. The upgrade of the present MOPOS aims at developing a radiation hard electronic system capable to provide both high dynamic range measurements to cover the various beam configurations available on the SPS and a fast enough data sampling rate to resolve the 2 μs long multi batch structure of the beam.

The analogue part of the Front-End (FE) board is based on dual Logarithmic Amplifiers (LA), which provide a direct measurement of the beam position. For each BPM, the input stage is made of a low-pass filter that minimizes the bunch shape variation during acceleration, followed by band-pass filters, which create suitable signals for the LAs. Three LA stages are necessary to cover the large SPS dynamic range related to different kind of particles, energies, and filling schemes. Each plane generates three analogue position signals, called Delta 200 MHz, Delta 40 MHz Low Sensitivity and Delta 40 MHz High Sensitivity. In addition, the summation of each LA output provides an estimate of the beam intensity measurement, which is used to detect the beam presence and validate the acquisitions.

The digital part of the FE board consists of an octal 14-bit ADC (Analog Devices), an FPGA (Xilinx Spartan6) and a Small Form-factor Pluggable (SFP) optical transceiver. Analogue data are digitized at 10 MS/s and serialized. In the FPGA, each ADC measurement is tagged with a time-stamp with respect to the rising-edge of the SPS turn-clock. Data are then packed in a frame every turn and transmitted to the readout board using a 2.4 Gb/s optical transmission link.

The first FE prototype, installed out of the ring and connected to a "shoe-box" (vertical BPM) and to a Stripline (horizontal BPM), has been successfully tested with beams on the SPS [1]. The radiation tests done to validate some of the commercial components of the FE board are described in this paper.

LOGARITHMIC AMPLIFIER, ADC DRIVER AND VOLTAGE REGULATOR RADIATION TESTING

The Devices Under Test (DUTs), Logarithmic Amplifiers (LA), ADC drivers (ADC-D) and voltage regulators (VR), are all soldered on the same analogue test board (see Fig. 1). Since the working total dose foreseen in the SPS is about 100 Gy/year, the total dose targeted for the irradiation test is 1 kGy per DUT.

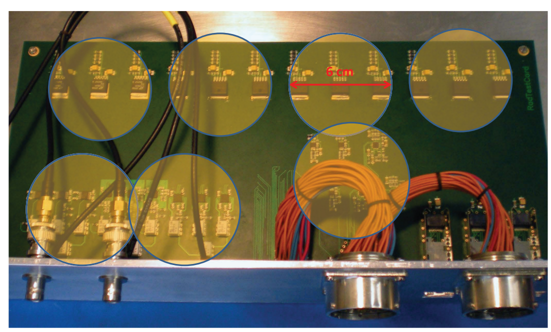

Figure 1: Analogue test board developed for the LA, ADC-D and VR Radiation Test at PSI.

Test Setup

The devices tested at PSI at the Proton Irradiation Facility (PIF) under very stable beam conditions are listed in Table 1. The beam conditions used during the test are presented in Table 2, each DUT being exposed to the Total Dose of 1 kGy accumulated over 3.5 hours.

The analogue test board is composed of 3 units of each DUT for reproducibility and statistical reasons. The test is then performed moving the proton beam across the board over seven different zones as shown in Fig. 1.

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The analogue test board is powered by a custom-made power supply located in an adjacent technical room and therefore not exposed to radiation. The power supply is switched-off every 60 minutes to avoid latch-ups. The acquisition of each DUT output voltage is performed every 3 minutes using a Keithley multimeter, remotely controlled by LabView.

Table 1: LA, ADC-D and VR Radiation Test: DUTs.

Device	Company	DUT
Logarithmic Amplifier	Analog Devices	AD8302
	Analog Devices	ADL5519
	MAXIM	MAX2016
ADC Driver	Analog Devices	ADA4932-2
	Texas Instruments	THS4521
Voltage Regulator	Linear Technology	LT1963AEQ
	Texas Instruments	TL1963-KTT
	Texas Instruments	LP3875-ADJ
	Texas Instruments	TPS7A4501KTT

Table 2: LA, ADC-D and VR Radiation Test: Beam Conditions.

Particle Type	proton
Energy [MeV]	230
Flux [p/cm^2/sec]	1.6 10^8
Collimator [cm]	5.8
Fluence [p/cm^2]	1.874 10^{12}
Angle [deg]	90

Test Results

The logarithmic amplifiers and the ADC drivers have not shown any sign of failures nor deterioration. The output voltages remain the same with respect to the reference values, measured both during and after irradiation [2].

The test of voltage regulators has indicated that they are quite sensitive to radiation. Depending on the type of component, the output voltage starts drifting with respect to the expected value. Voltage regulators TL1963-KTT and TPS7A4501KTT have shown for all components very little output voltage variation, lower than 100 mV over 3.5 V. This would correspond to a change in Voltage of 2 % over 10 years in the SPS. The LP3875-ADJ have presented a behavior worse than the previous components with voltage drifts as high as 700 mV for all 3 components. The test of LT1963AEQ is not conclusive since one component died after only about 100 Gy of irradiation while the two others have shown a relatively good resistance to radiation.

SFP RADIATION TEST

Small Form-factor Pluggable (SFP) optical transceivers, listed in Table 3, have been tested up to a total dose of 1 kGy. A dedicated test bench has been developed and installed at PSI PIF and at CERN CNRAD (TSG 45, Area 451) facilities. The experimental apparatus used in both cases is very similar as described in the next paragraph.

Table 3: SFP Radiation Test: DUTs. All components are single-fiber except FTTX-FT3A05D.

Company	DUT	Tested PSI	Tested CNRAD
FTT double-fiber	FTTX-FT3A05D	5	1
FTT	FTTX-FTA05D-35	-	2
	FTTX-FTA05D-53	-	2
Ligent	LTE5350-BC	3	1
	LTE3550-BC	1	1
Source Photonics	SPL-35-GB-CDFM	2	2
	SPL-53-GB-CDFM	3	2
Yamasaki	541315L-15B	1	-
	541315L-15Y	1	-
Lightron	WSP24-313LC-I5A	2	2
	WSP24-513LC-I3A	3	2
Huihong	HGLC-BX-D	-	1
	HGLC-BX-H	-	1

Test Setup

The SFP-Test board supports 20 SFP cages, as depicted in Fig. 2, but only the SFPs under test were plugged. At PSI up to 3 DUTs were exposed to radiation at the same time while at CNRAD all the 12 DUTs were tested in parallel. The SFPs convert optical signals into electrical signals or vice versa. On the PCB the electrical TX (transmission) and RX (reception) channels are in loop-back configuration and the data coming from the read-out board are simply retransmitted.

During the test at PSI, the power supply board was located in a safe room, not exposed to radiation, while at CNRAD it was sitting nearby the SFP-Test board inside the irradiation facilities. The power supply board was remotely switched off and on in case of latch-ups, which happened a few times.

The read-out board (see Fig. 3) is a custom made VME FMC carrier, called VFC [3], which has been developed as a general beam instrumentation acquisition board. On the VFC there are two Xilinx Spartan6, configured to manage the 6 SFPs modules pluggable on the board: 2 on the front panel and 4 on the two FMC mezzanine boards. Each test line is independent from the others. Once the communication between the read-out and the front-end optical link is established, the VFC generates a frame of 32-bit

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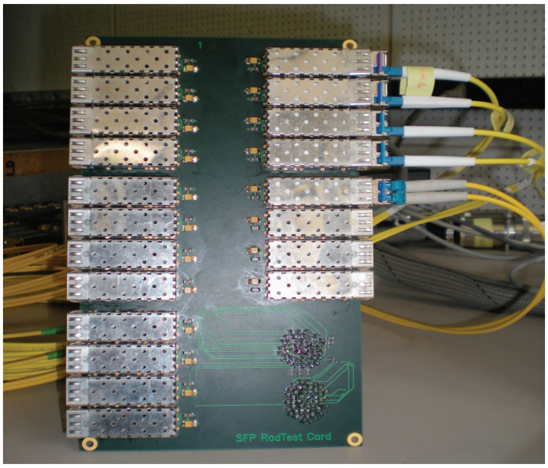

Figure 2: SFP-Test board developed for the SFP Radiation Test.

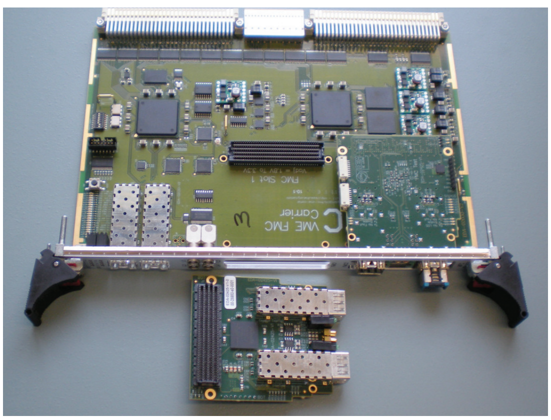

Figure 3: VFC read-out board used for the SFP Radiation Test.

words in free running mode. This frame is sent to each SFP, which transmits it back to the VFC board at a communication rate of 1.25 Gb/s. The FPGA in the VFC cross-checks the validity of data sent and received back at a rate of 31.25 MHz. The firmware identifies Single Event Upset (SEU) or Multiple Bit Upset (MBU), with respectively one bit-error or multi-bit errors on the 32-bit word received back from the DUT. Three 8-bit counters are implemented to monitor both single, multiple and the total numbers of errors. All the FPGA settings and the data read-back are managed via the VME interface through a CAEN USB-VME bridge (PSI) or through a MAN CPU (CNRAD). The control of the VME interface is performed using a Python script which reads back the counters every second. A report file is then uploaded if the values of the counters change or if the communication is interrupted. Once the "total error" counter reaches its maximum value (255 counts), the program reset the communication protocol, clears the counters and restarts the measurements. In addition a Keithley multimeter controlled by LabView reads the front-end TX and RX voltage values which are only used for monitoring purposes during the runs. The time interval between two acquisitions can be set via software, typically 3 minutes at PSI and 30 minutes at CNRAD.

The irradiation conditions for the two tests are very different and summarized in Table 4.

Table 4: SFP Radiation Test: Beam Conditions

	PSI	CNRAD
Particle Type	proton	mixed
Energy [MeV]	230	-
Flux [p/cm^2/sec]	$1.2\ 10^7 \div 1.7\ 10^8$	-
Collimator [cm]	5.8	-
Angle [deg]	90	-
Mean Dose Rate [rad/s]	$0.6 \div 9.5$	0.005
Total Dose Rate [rad]	$(12 \div 820)\ 10^2$	$0.35\ 10^5$

Test Results

For each DUT the measurements have been analyzed and are presented plotting the Total-error as a function of the Total-dose. As an example some data of PSI and CNRAD are respectively presented in Fig. 4 and in Fig. 5. As a general trend, the same components present similar behavior in both cases. In addition to the SEU and MBU errors, an unexpected behavior, referred herein as *step-error*, has been observed during both tests. It refers to consecutive readings of a full counter, which we interpret as a major failure rate that our setup cannot quantify precisely. The error rate is in this case higher than $8.16\ 10^{-6}$.

Another failure mode, observed both at PSI and CNRAD, appears as a definitive loss of communication, which typically indicates the death of the component.

For each DUT, the Cross-section [Number of Errors / (p/cm^2)] has been estimated and the results can be found in [4] for PSI and in[5] for CNRAD.

At PSI, the Ligent LTE3550-BC did not work at all under radiation. Ligent and Yamasaki components are in general quite sensitive to the irradiation, working at best up to 300 Gy and 80 Gy respectively. SFPs from Source-Photonics resist up to 350 Gy but with *step-errors*. Double-fiber FTT and Lightron-I3A SFPs are more promising as they showed a good radiation resistance up to 300 Gy and 800 Gy respectively.

Concerning the test performed at CNRAD, Huihong SFPs have been rejected, since they had a mechanical issue with the fiber connection, producing error counts even without radiation. Ligent SFPs work up to 250 Gy, but produce many *step-errors*. FTT double-fiber and Source Photonics SFPs keep working correctly up to 250 Gy and 200 Gy. Single-fiber FTT SFPs (with almost no *step-errors*) and Lightron SFPs (with few *step-errors*) present

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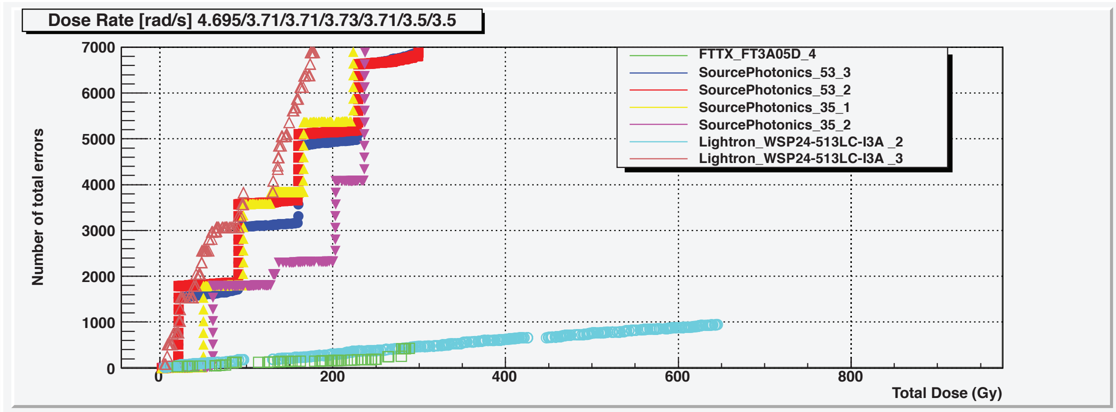

Figure 4: SFP data from Radiation Test at PSI. Vertical holes are *step-errors*, horizontal holes are missing data.

the best radiation hardness with no degradation throughout the whole run (up to 350 Gy).

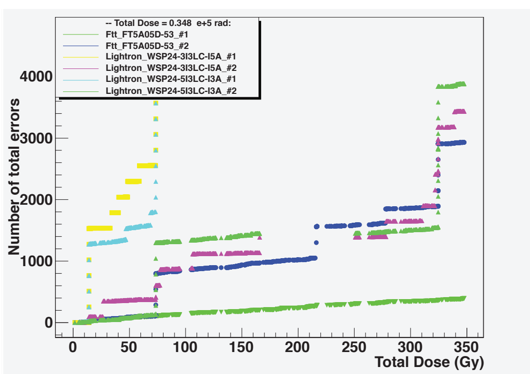

Figure 5: SFP data from Radiation Test at CNRAD. Vertical holes are *step-errors*, horizontal holes are missing data.

CONCLUSIONS

The Logarithmic Amplifiers and the ADC-Drivers have withstood radiation doses up to 1 kGy without any sign of degradation (see Table 2). The measured voltages remain constant with respect to the reference values measured in our laboratory, both during and after the irradiation [2]. Voltage regulators TL1963-KTT and TPS7A4501KTT have shown very little output voltage variation during the test. Any of these components can be selected for our application.

The SFP optical transceivers are in general much more sensitive to radiation (see Table 4). For all the components tested, multi-bit errors dominate [4] [5]. Many SFPs have shown very high failure rates, visible in our analysis as *step-errors*, for which our test setup cannot precisely measure the error count. Only 2 SPFs (FTT and Lightron) families tested here have shown a good radiation hardness up to 350 Gy. For our current renovation program of the SPS BPM front-end electronics, we are now considering to use specifically designed radiation hard optical transceivers rather than COTS components.

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