Journal of
Instrumentation

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Published by IOP Publishing for Sissa Medialab

Received: *October 22, 2024*
Accepted: *December 19, 2024*
Published: *January 17, 2025*

Topical Workshop on Electronics for Particle Physics
University of Glasgow, Scotland, U.K.
30 September–4 October 2024

TID damage assessment on LVDS links for the ATLAS muon barrel spectrometer readout system

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Abstract: This work reports on Total Ionizing Dose (TID) assessment on off-the-shelf LVDS links that will be used for the new trigger and readout system of the ATLAS muon barrel spectrometer within the HL-LHC program. We developed an experimental setup that allows to investigate TID effects on the currents drawn by the devices under test and on their signal integrity, including variations in amplitude, rise/fall time, and bit error rate. No significant variations of these quantities has been observed after integrating the ATLAS target dose of 84.6 Gy. In order to investigate high-dose effects, the irradiation has been extended up to 15.4 kGy. No post-annealing effects were observed. These results complement existing literature, proving the robustness of off-the-shelf LVDS links for the ATLAS environment.

Keywords: Front-end electronics for detector readout; Radiation damage monitoring systems; Radiation damage to electronic components; Radiation-hard electronics

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https://doi.org/10.1088/1748-0221/20/01/C01023

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Contents

1 Introduction

High Luminosity-Large Hadron Collider (HL-LHC) will operate with pp collisions at an instantaneous luminosity up to $L = 7.5 \times 10^{34}\ \mathrm{cm^{-2}\ s^{-1}}$, increasing pile-up and radiation levels [1]. To address these challenges, ATLAS detectors will undergo upgrades. In the ATLAS muon barrel spectrometer, new Data-Collector-Transmitter (DCT) boards [2–4] will be installed to process hit data from Resistive Plate Chambers (RPCs). DCTs will receive signals from the RPC front-end strips, adapt them to the Low Voltage Differential Signaling (LVDS) standard, apply zero-suppression algorithm, and transmit data to the Barrel Sector Logic (SL) via optical links. Figure 1 shows a) the position of a DCT on an RPC and b) an image of the DCT itself.

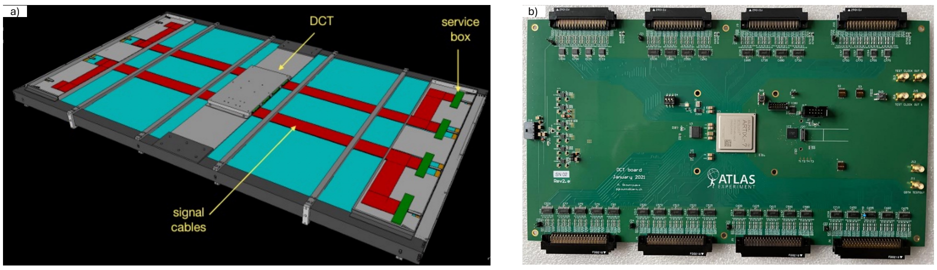

Figure 1. a) Position of the DCT board on a RPC of the ATLAS muon barrel spectrometer; b) DCT prototype.

A total of 1546 DCT boards will be part of the ATLAS muon trigger front-end electronics [2]. We are currently involved in the radiation qualification of DCT components. The operation of DCT must be guaranteed at the radiation levels reported in table 1, where $\Phi_{1\,\mathrm{MeV\ n.eq}}$ is the 1 MeV equivalent neutron fluence and HEH is the High-Energy Hadron equivalent fluence [5].

Table 1. Radiation levels required for the DCT operation.

TID (Gy)	$\Phi_{1\,\mathrm{MeV\ n.eq}}$ ($\mathrm{cm^{-2}}$)	HEH fluence ($\mathrm{cm^{-2}}$)
83	4.2×10^{12}	1.24×10^{12}

This work describes the experimental procedures and results of a TID test on off-the-shelf LVDS links.

2 Materials and methods

The experimental setup for the TID assessment features three boards developed at the INFN Naples Unit. An input board is connected to an Agilent N6705B DC Power Analyzer, which supplies voltage and measures the current drawn by the Devices Under Test (DUTs). A Tektronix AFG31152 Function Generator provides K28 commas in the 8b/10b protocol at a frequency of 3.3 MHz. It also outputs a clock signal used to trigger the oscilloscope. An LVDS driver (SN65MLVD047A) on the input board converts the single-ended stream from the Function Generator into four differential outputs, which are transmitted to the DUTs via a 4-meter long flat cable. The DUTs board contains ten LVDS receivers (DS90LV048ATM/NOPB), according to the ATLAS radiation qualification standards. Each receiver handles four differential input signals, allowing for a total of 40 single-ended outputs. A MUX board, equipped with four 16-to-1 analog multiplexers (ADG706BRUZ) and a Raspberry Pi 3 Model B+, enables the four gates of a specific DUT to drive a 4-channel oscilloscope via another 4-meter long flat cable. LVDS driver, LVDS receivers, MUXs, and Raspberry Pi are powered on separate bias domains in order to allow the current analysis of the DUT.

Figure 2 summarizes the experimental setup. The operation of the MUX board is illustrated in figure 3 that shows the connections between the four MUXs with the ten DUTs (#1 to #10), the Raspberry Pi GPIO pins driving the MUXs address bus (A0, A1, A2, A3), and the four channels (A,B,C,D) of the oscilloscope. Remote selection of a DUT is controlled via a Python script running on the Raspberry Pi. The script cycles through the DUTs by setting the 4-bit address bus. In this way, one DUT at a time is connected to the oscilloscope. Each DUT remains selected for a programmable amount of time, followed by a deselection period whose width in seconds matches the DUT number (e.g., before selecting DUT#5, all DUTs are deselected for 5 seconds). Such a deselection is visible in the current trend and it acts as a label for tagging the DUT.

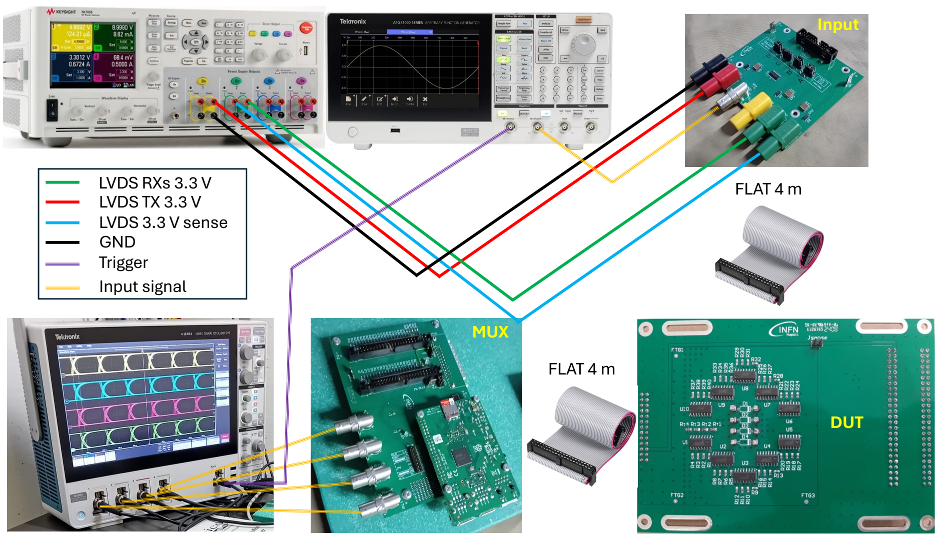

Figure 2. Scheme of the experimental setup for the TID test of LVDS receivers. Connections are color-coded.

TID damage assessment was performed at the CERN CC60 facility [6] that is equipped with a ~10 TBq ^{60}Co radioactive source. Two runs were conducted in a row: one at the ATLAS target dose of 84.6 Gy and dose rate of 27 Gy/h, and another at a high dose of 15.4 kGy and dose rate 364 Gy/h. On-DUT dose verification was achieved with radiochromic films [7]. These dosimeters

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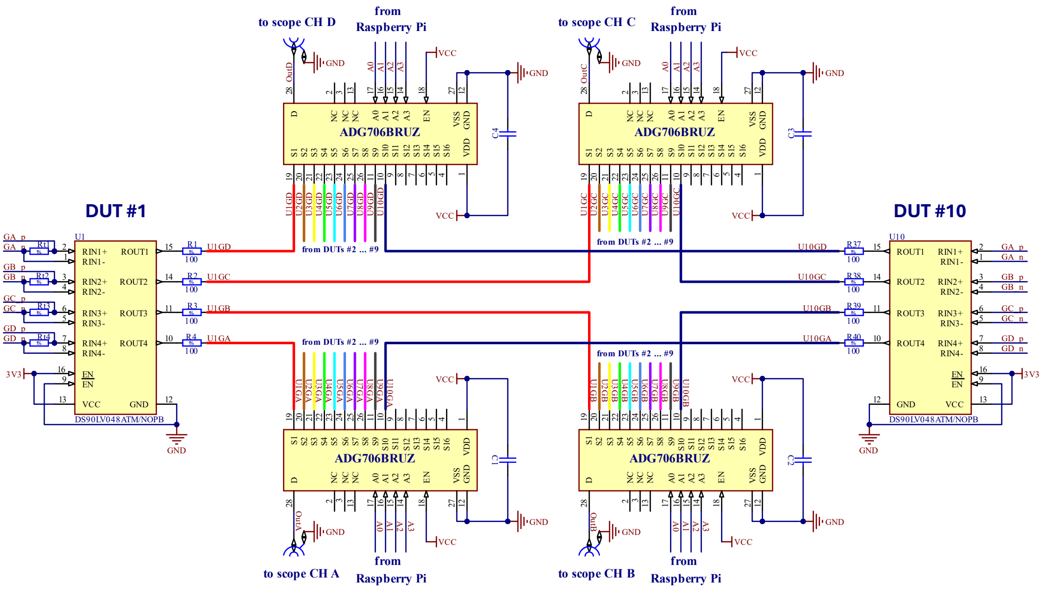

Figure 3. Connections between the MUXs and the LVDS receivers, the GPIO pins of the Raspberry Pi, and the channels of the oscilloscope.

polymerize and darken upon exposure to radiation, with the degree of darkening proportional to the absorbed dose [8]. For our experiments, we used HD-V2 Gafchromic films, which consist of a 12 µm active layer on a 97 µm polyester substrate. This type of film was chosen for its wide dynamic range, spanning from 10 Gy to 1000 Gy. A set of HD-V2 Gafchromic films from the batch # 06152302 was pre-calibrated at the 220 Nordion Gammacell, ^{60}Co source, of the Institute for Organic Synthesis and Photoreactivity (ISOF-Bologna) at the National Research Council of Italy (CNR). Figure 4 shows a) the DUTs board with the HD-V2 film in the CERN CC60 irradiation room, and b) a thermal image. The thermal image indicates that the DUTs temperature was approximately 23°C. Temperature was also monitored with Si diode sensors operated in constant forward bias [9], mounted on the pads D1, D2, D3, D4 of the DUTs board of figure 2. The whole setup but the DUTs board was kept in a buffer zone outside the irradiation room where the dose rate was 160 µGy/h.

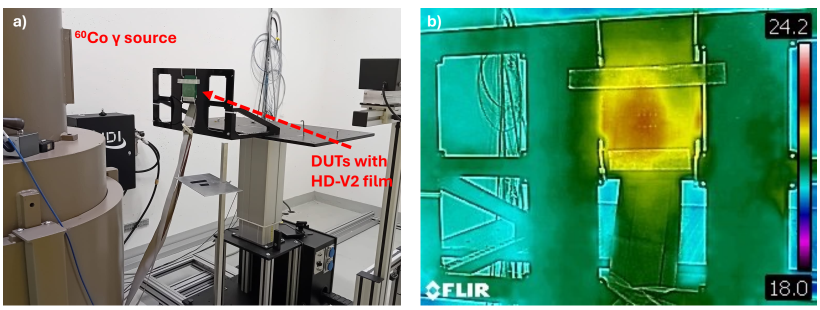

Figure 4. a) CERN CC60 irradiation room with the DUTs board and the HD-V2 film. b) Thermal image of the DUTs board.

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3 Results

The current drawn by LVDS receivers for the irradiation at 84.6 Gy is reported in figure 5(a). The irradiation began after 12 minutes from the start of data acquisition and concluded at 200 minutes, integrating a total dose of 84.6 Gy. The observed trend in figure 5(a) reflects the DUTs selection/deselection pattern discussed in section 2. Specifically, each DUT is selected for 5 minutes and deselected for durations from 1 second to 10 seconds, depending on the DUT number. Figure 5(b) provides a close-up of the plot of figure 5(a) between 154.5 and 166.0 minutes. LVDS receivers current remained constant over the irradiation with an average value of (121.7±0.05) mA, when DUTs were selected, and (118.8±0.05) mA, when no DUTs were selected. Current drops induced by changes of room temperature were observed at 74, 135, and 215 minutes. The inset of figure 5(a) displays a close-up view of the current trend around the drop at 135 minutes. The current drop lasts about 3 minutes and is fully recovered after 20 minutes. Figure 6 shows the eye-diagrams of K28 streams for the four outputs of a given DUT. For each signal, we measured the amplitude, unit interval, rise time and fall time obtaining average values of 3.25 ± 0.01 V, 312 ± 6 ns, 73 ± 2 ns, and 58 ± 2 ns, respectively. The bit error rate, evaluated with a Python script, was found to be less than 1×10^{-12}. These values, measured before irradiation, remained unchanged within the experimental uncertainties also after irradiation.

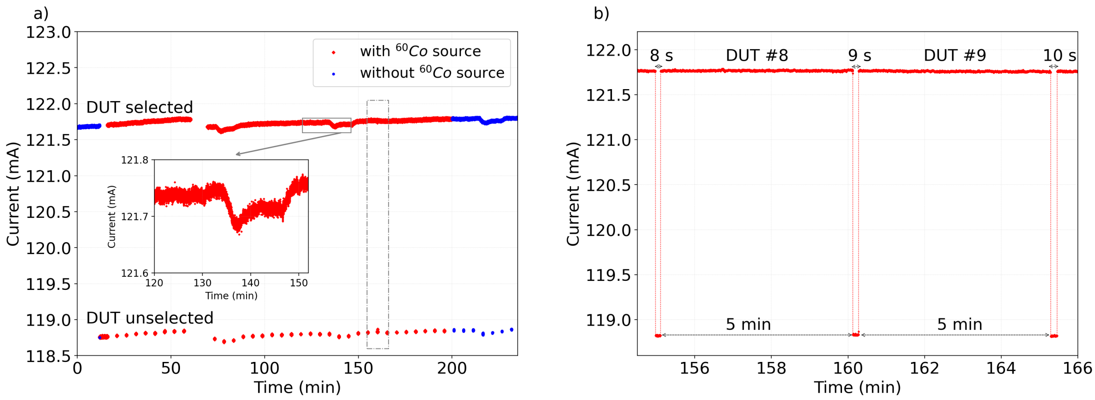

Figure 5. a) Current drawn by LVDS receivers vs. time with the inset highlighting a temperature-induced current drop; b) close-up of the dashed rectangle in (a).

LVDS links are widely used in many experiments and custom devices with extended common mode capability (from -7 V to +12 V) have been produced for space applications. Results of a TID test on such LVDS links have been reported in [10]. Changes in power consumption and leakage currents have been observed from 560 Gy, together with a significant reduction of the common mode voltage range. Therefore, we investigated the common-mode voltage range just after the high-dose irradiation at 15.4 kGy. With 200 mV differential input signals, the highest common-mode voltage before failure was measured to be 3.6 V. This value significantly exceeds what is specified in the datasheet (2.3 V). Figure 7 shows the output of the LVDS receiver when violating the common-mode voltage.

All the DUT timing characteristics did not change after the irradiation at 15.4 kGy. Finally, the DUT board underwent a post-irradiation annealing process at the INFN Rome Unit for 7 days at 100°C. No change was observed after the annealing. An in-depth analysis of the radiation damage will be conducted by means of impedance spectroscopy techniques according to the framework developed in [11].

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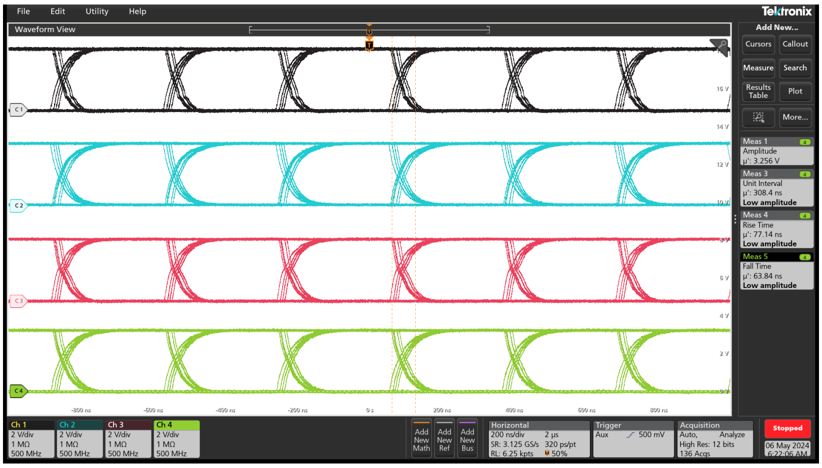

Figure 6. Eye-diagrams of single-ended signals of LVDS receivers outputs under TID test.

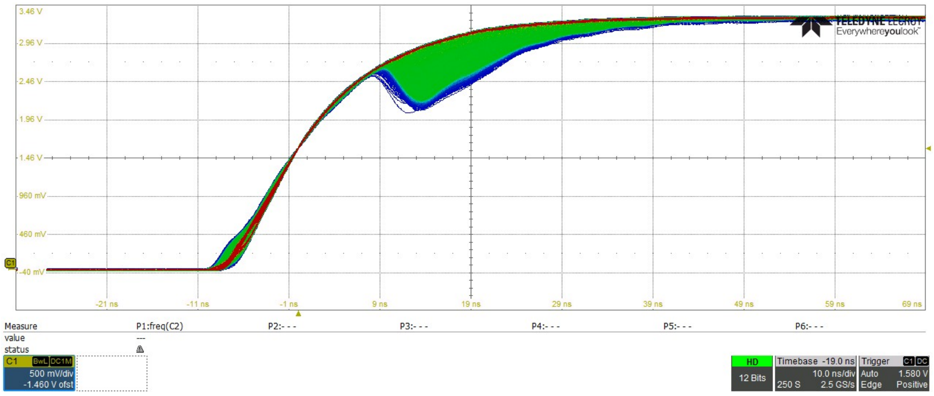

Figure 7. LVDS receivers output signal when common mode voltage is violated.

4 Conclusions

This study presents the TID qualification of LVDS links for the ATLAS muon barrel spectrometer for HL-LHC. We developed a versatile testing setup capable of measuring the current drawn by LVDS receivers, and key parameters such as amplitude, rise/fall time, and bit error rate. These parameters were found to be constant before and after irradiation. These findings complement existing literature and confirm the robustness of off-the-shelf LVDS links for use in harsh radiation environments.

Acknowledgments

We thank the CERN CC60 staff for the help during the irradiation.

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