Characteristics of the MTx optical transmitter in Total Ionizing Dose

HSTD13
Vancouver, Canada, Dec. 3-8, 2023

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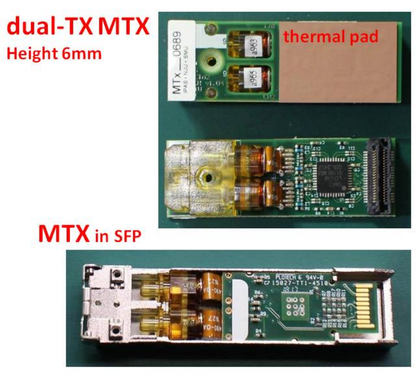
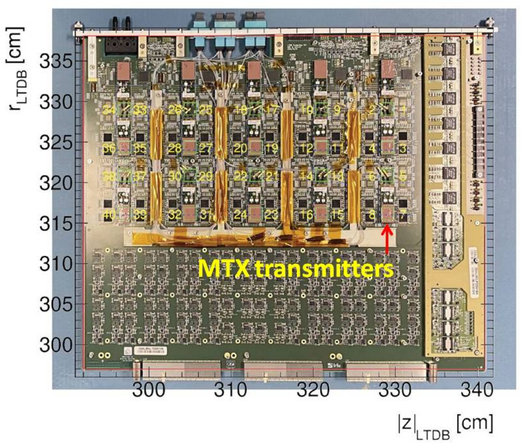
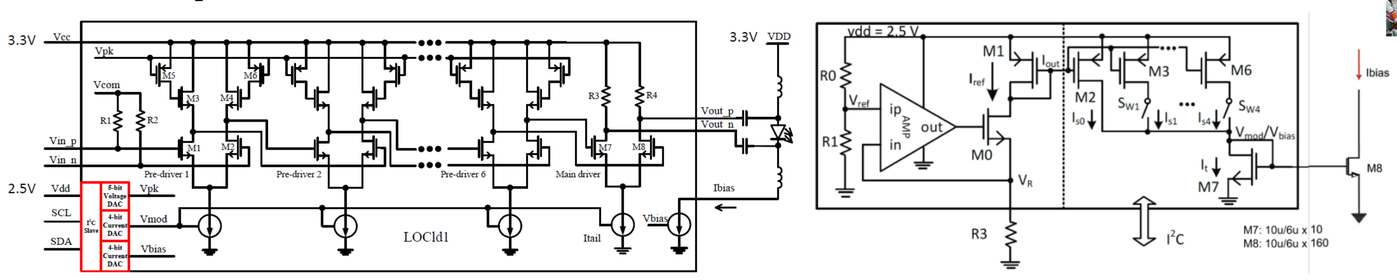
MTx[1-3] a dual channel multi-mode 850 nm Miniature Transmitter, for the Liquid Argon Calorimeter (LAr) and the New Small Wheel (NSW) of ATLAS, is investigated for rad-hard of **Total Ionizing Dose (TID)** with **X-ray** and **Co-60** gamma-ray. Components tested include: **VCSEL** (Vertical Cavity Surface Emitting Laser) and the **LOCld** laser driver. MTx operated at **5.12 Gbps** is expected for TID of **1 kGy** after **4000 fb^{-1}** at high luminosity LHC.





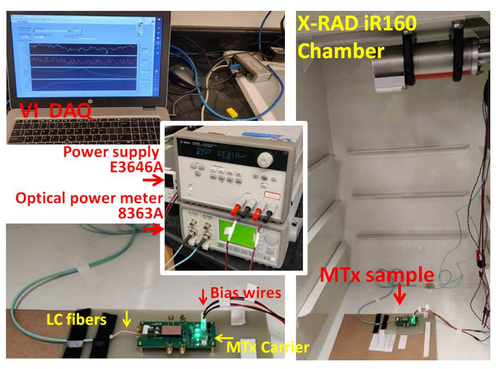
(Left) MTx in miniature height for LAr and SFP (for NSW) formats;
(right) MTx's on the LAr calorimeter motherbord inside the ATLAS, rad-hard to TID is required for 1 kGy.

LOCld laser driver ASIC[4] is developed in 0.25 μm CMOS Silicon on Sapphire technology. Two bias voltages, 3.3 V and 2.5 V, supply laser current outputs and I^{2}C control. The CMOS is known for damage in TID. The M7 NMOS, collecting I_t total current, has a smaller implantation size. It is suspected for sensitive to TID.

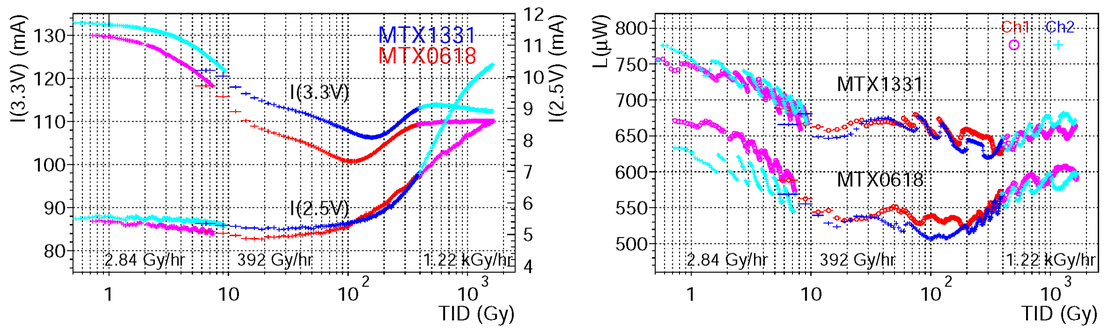


(left) LOCld laser driver schematics, with ***(right)*** the TID sensitive portion shown

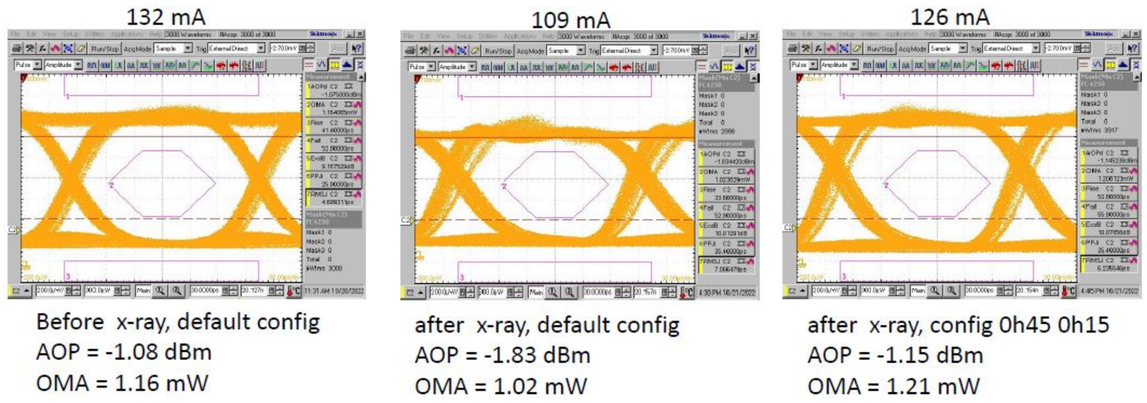
MTx in X-ray tests were conducted. Bias currents of 3.3 V and 2.5 V and VCSEL light outputs were monitored during TID for degradation characteristics.



TID in a X-RAD iR160 chamber
MTx irradiated at increasing dose rates, accumulated to 1.62 kGy.



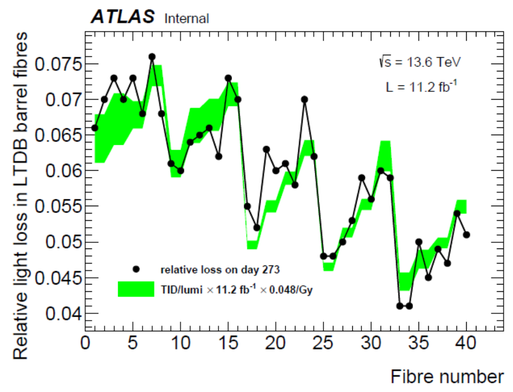
Two MTx's tested in X-ray, accumulated at 3 dose rates, to 1.62 kGy
(left) bias currents of 3.3 V and 2.5 V; ***(right)*** optical powers. Degraded and saturated ~100 Gy.



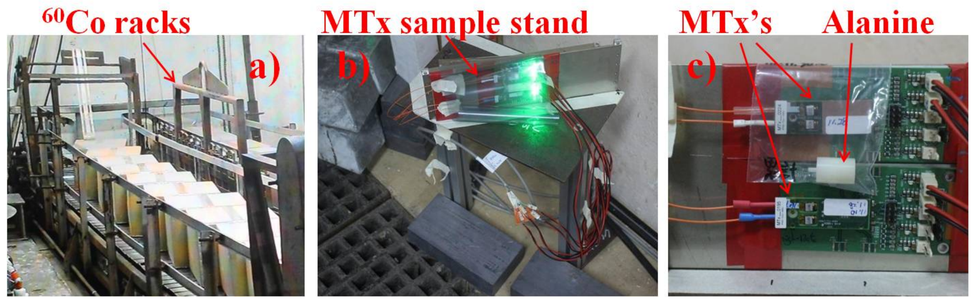
MTx eye diagrams at 5 Gbps, before/after X-ray TID of 1.62 kGy
(left) before TID at nominal I^{2}C, I(3.3V)=130 mA; ***(middle)*** after TID, nominal I^{2}C, I(3.3V) dropped to 109 mA, eye-AOP dropped by -0.8 dBm; ***(right)*** by I^{2}C setting higher modulation, I(3.3V) increased to 126 mA, eye-AOP restored. Eyes are nosier after TID.

Degradation at LAr[5] ATLAS Run-3 stared in July 2022, MTx's show optical power degradation with initial radiation.

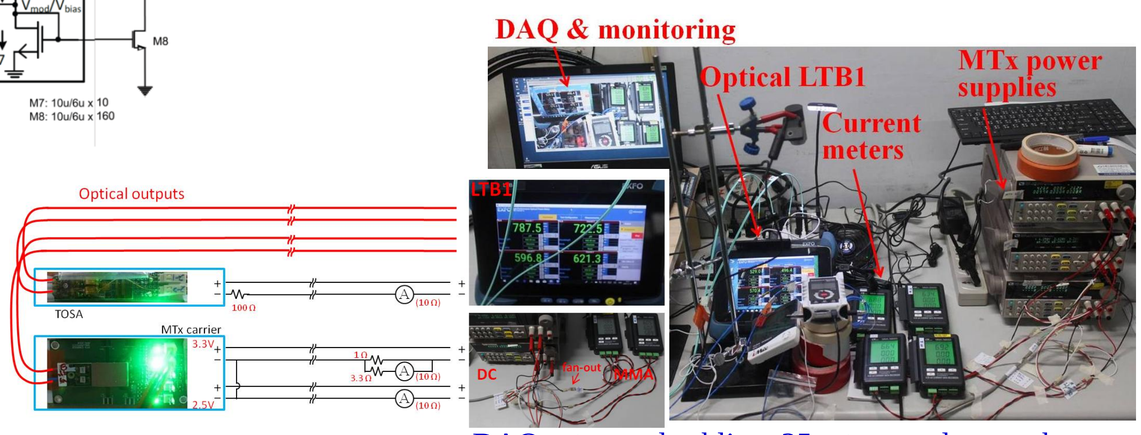
MTx light powers (data points) are monitored, degradation by 7.5 % highest is observed after 11.2 fb^{-1}. The TID (green filled) is estimated by MC to be around 0.14 Gy/fb^{-1} (highest).



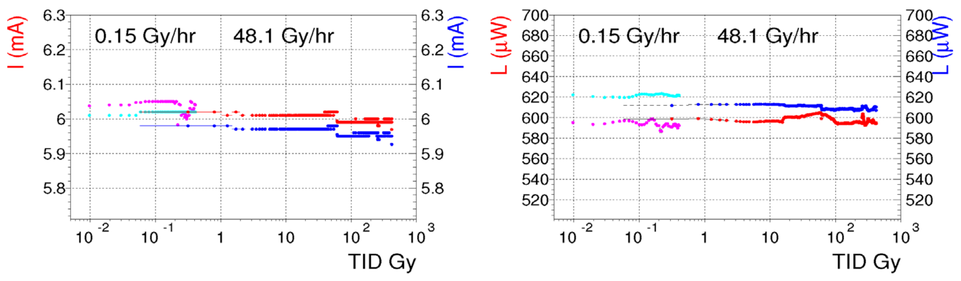
Co60 test at INER compare to X-ray of lower gamma energy, dose rate dependence of 0.15, 2, 20, 50 Gy/hr. Dose rate control by distance, Pb shield to a Co60 rack. Online DAQ is 35 m to samples. Bias 3.3 V, 2.5 V currents, TX optical powers recorded. TID accumulated up to 1 kGy.



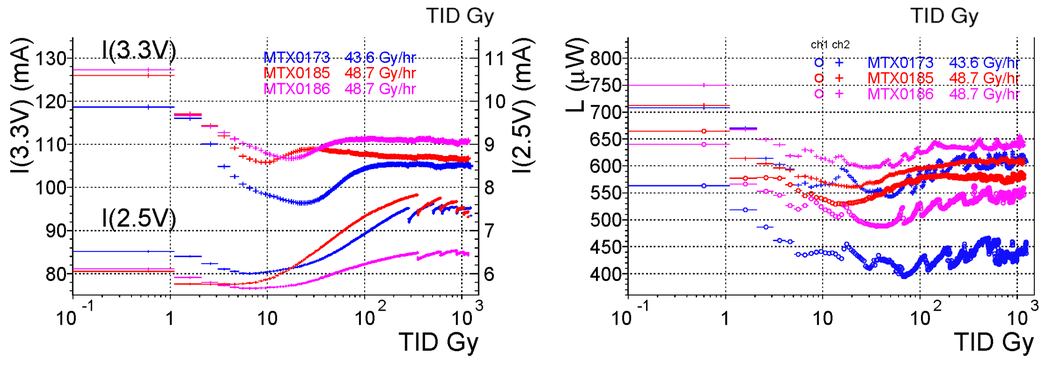
a) Co60 rack between service rail b) MTx sample in irradiation area
c) two MTx test modules with an Alanine (for TID dose calibration).



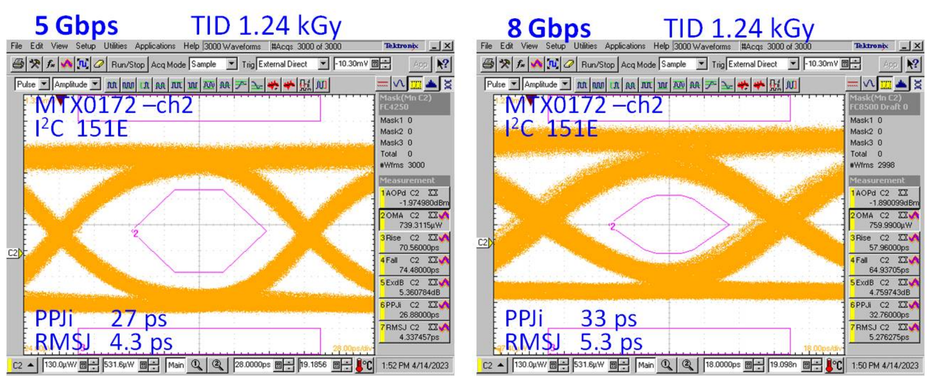
DAQ setup and cabling, 35m to samples are shown.
Currents were recorded by MMA-386SD , Light powers recorded by LTB1



Two VCSEL's irradiated in Co60 at fixed bias at low/high dose rates. No degradation observed for the currents and light powers. The steps in plots are caused by accesses fumbling fibers.



Three MTx's tested in Co60, high dose rates, accumulated to 1.24 kGy
(left) bias currents of 3.3 V and 2.5 V; ***(right)*** optical powers.



MTx eye diagrams after Co60 TID to 1.24 kGy: ***(left)*** 5 Gbps and ***(right)*** 8 Gbps
I^{2}C on modulation is optimized, Although jitter increased after TID, 8 Gbps is qualified.

Summary degradation of LOCld laser currents at the initial TID around 100 Gy. Anneal with additional TID to 90 % of the original. X-ray, Co60 results are compatible, no rate dependence noticed. By I^{2}C configuration on modulation to raise current. Eye-diagram after TID has high jitter. Irradiated samples are qualified for 5 Gbps applications at ATLAS.

[1] *"Component Prototypes Towards a Low-Latency, Small-Form-Factor Optical Link for the ATLAS Liquid Argon Calorimeter Phase-I Trigger Upgrade"*, IEEE Trans. Nucl. Sci. 62 (2015) 250.
[2] *"Mid-board miniature dual channel optical transmitter MTx and transceiver MTRx"*, JINST 11 (2016) C03054.
[3] *"Aging and Environmental Tolerance of an Optical Transmitter for the ATLAS Phase-I Upgrade at the LHC"*, Nucl. Instr. and .Meth. A831 (2016) 349.
[4] *"8-Gbps-per-channel radiation-tolerant VCSEL drivers for the LHC detector upgrade"*, JINST (2015) 10 C02017.
[5] *"LTDB power loss versus TID"*, LAr Phase I meeting, S. Menke, 2022, Oct. 26.