Optical transceivers for event triggers in the ATLAS phase-I upgrade

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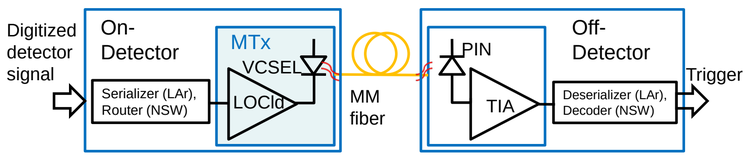
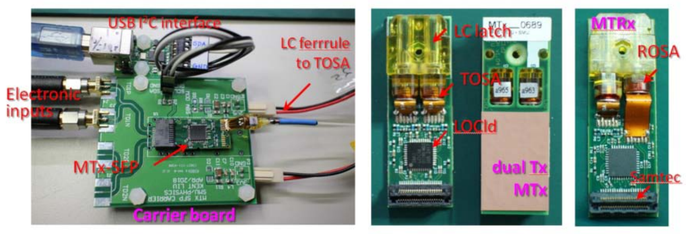
Introduction: the dual-channel optical transceivers MTx, MTRx are fabricated for the phase-I upgrade of the ATLAS trigger electronics in the Liquid Argon Calorimeter (LAr) and the Muon New Small Wheel (NSW) Spectrometer [1,2]. The opto-electronics employed are the 850 nm multi-mode VCSEL (vertical cavity surface emitting laser) and a LOCld laser driver made of 0.25 μm Silicon-on-Sapphire (SoS) CMOS process [3].



Optical link for the ATLAS Phase-I upgrade of trigger electronics.

MTx, MTRx modules are assembled with a LC latch to a reduced 6mm height for LAr [4], and in the commercial SFP+ format for NSW. The Rx channels are ROSA's with the photo detector current amplified by a CERN developed TIA. The components are investigated for ageing and radiation tolerance [5]. The LOCld driver is configured by I²C for the VCSEL bias, output peaking and modulation.



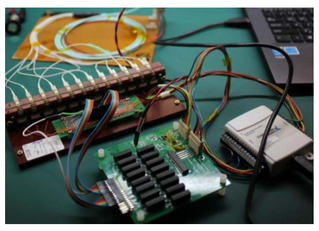
The MTx, MTRx for LAr are package with a customized LC latch to a total 6 mm in height.

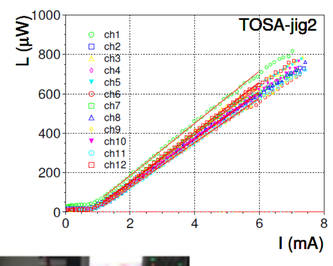
SFP+ type MTx

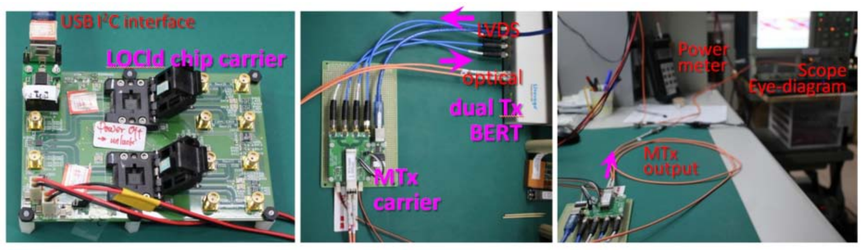
Test setup on carrier board is shown for the SFP+ type MTx. The carrier provides USB interface to PC for I²C control, and inputs of electrical signals.

Quality Assurance requires LOCld chips checked for currents and I²C communication. TOSA's are measured for L-I curves. The assembled PCBs are tested before/after TOSAs being soldered. Complete modules are examined for currents, Tx outputs free of 10 Gbps Bit-Error $<10^{-12}$, light-powers and eye-diagrams. Channels failed Bit Error is less than 1%. The eye-diagrams of 10 Gbps tests show a margin of 18 %

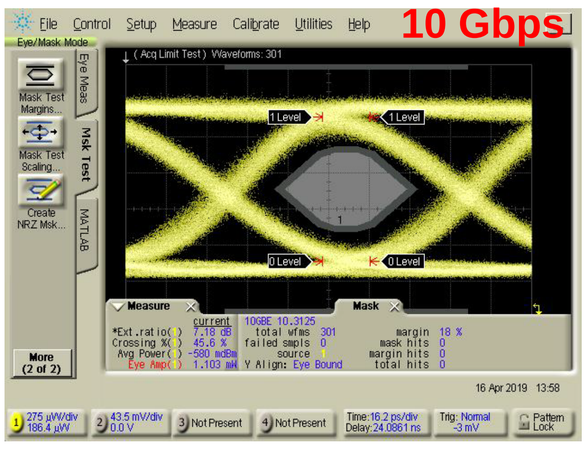
The Jig and DAQ setup measuring TOSA L-I-V is shown. Light power at 6 mA between 550 μW to 800 μW is required for module production.





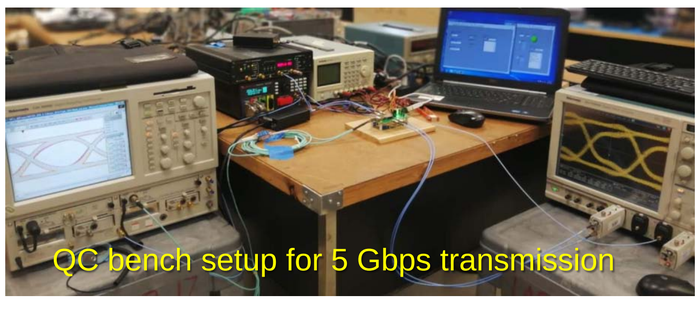


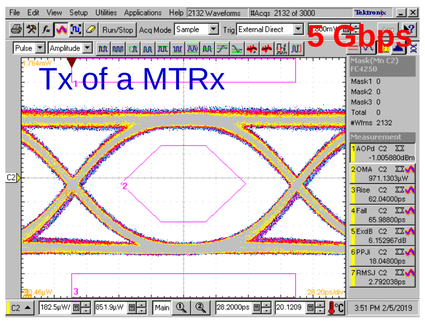
The LOCld chips are tested for currents and I²C function (left). The assembled modules are tested for Bit-Error (middle), light power and eye-diagram (right).

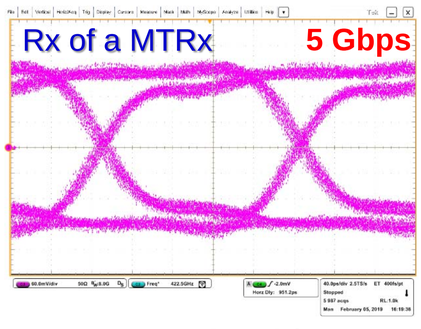


Eye-diagram of a MTx-SFP+ channel at 10 Gbps. The average power is 870 μW with the amplitude of 1.1 mW. The margin to mask is 18 %.

Quality Control on modules is conducted for 5 Gbps data transmission in ATLAS applications. Eye-diagrams of Tx's and Rx's are examined. Bench setup and typical eye-diagrams are shown.



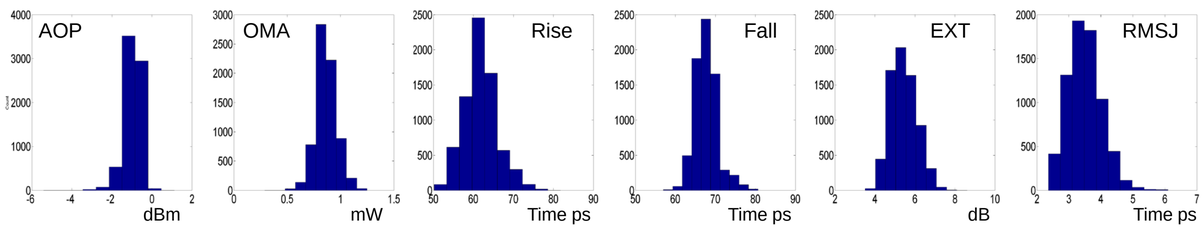




Bench setup for QC and example eye-diagrams of MTx, MTRx are plotted for data transmission of 5 Gbps at the LAr.

QC criteria on parameters of 5 Gbps eye-diagrams are listed. The yield for the total 3300 MTx and 800 MTRx modules produced for LAr is 99%.

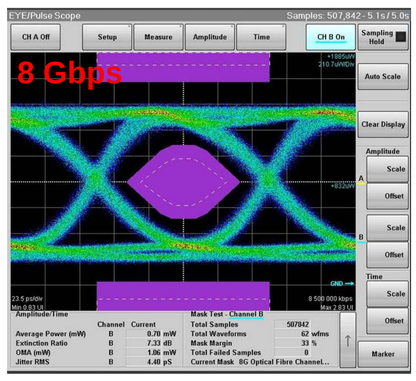
MTRx/MTx	AOP	OMA	Rise time	Fall time	EXT	RMJ
Criterion	> -3.5 dBm	>300 uW	<80 ps	<80 ps	>3dB	<4.5 ps



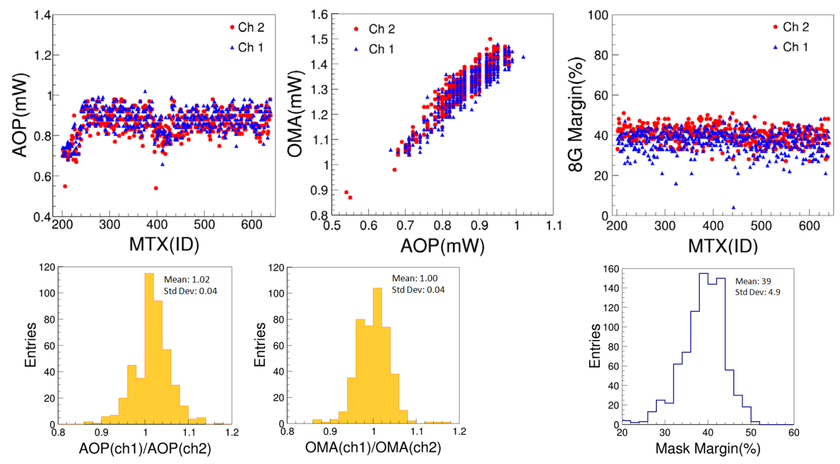
QC on thee MTx, MTRx eye-diagrams of 5 Gbps is shown for the criteria and the distributions. The yield is 99%.

AOP: Average optical power
OMA: Optical Modulation Amplitude
EXT: Extinction ratio
RMSJ: jitter RMS

Uniformity of transmitter channels is attended. The TOSA's for the two Tx's on a MTx driven by one LOCld are paired for equal light power within 3%. Performance is compared and illustrated for the 8 Gbps eye-diagrams conducted on the first batch of 440 MTx's. The ratios of both AOP and OMA between the two Tx's show RMS values of 4 %. The margins of 8 Gbps mask are uniformly distributed in 39 ± 5 %.

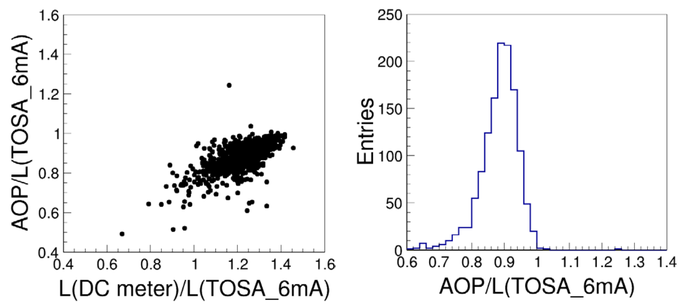


8 Gbps eye-diagram of a typical Tx channel.



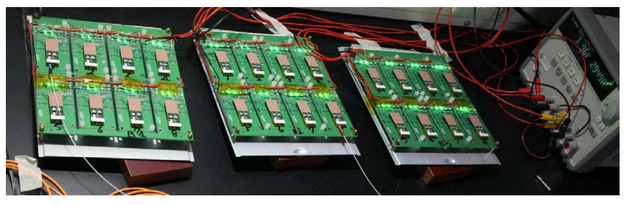
8 Gbps eye-diagrams measured for the first batch of 440 MTx's are analyzed for the AOP, OMA and the ratios between the two Tx's of each module. The TOSA's used are selected for intrinsic light power specified in 550 – 800 μW(at 6 mA). The LOCld's are configured for the same bias and modulation. The AOP of a Tx channel is approximately the light power of TOSA L-I for the LOCld bias current. The OMA shows a linear correlation to the AOP. The distribution of 8 Gbps eye-diagram margins to the mask is uniform around 39 %.

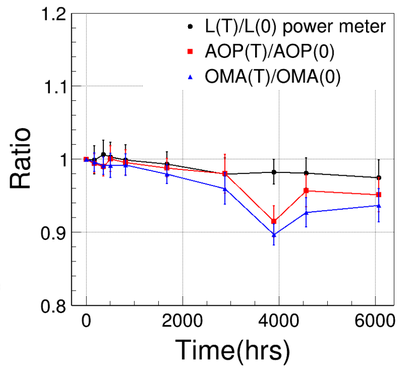
Measurement of optical power shows a large uncertainly dominated by the light coupling of fiber ferrules to TOSA's and to receivers. The MTx outputs are also measured with DC power meters. The deviation indicates a systematic uncertainty of 6 % on fiber light power measurements.



AOP of eye-diagrams of the SFP type MTx's are compared to the readings of DC power meter and the TOSA L-I at 6 mA (measured before assembly). The offset of means to 1 is due to calibration of the scope receiver, and the LOCld bias to TOSA being higher than 6 mA.

Ageing of MTx is monitored with burn-in of 24 modules in room condition. Bit-error rate at 10 Gbps and eye-diagrams are measured periodically. The burn-in has accumulated more than 6000 hours with no error observed. The power meter readings and eye-diagrams of AOP and OMA are compatible to initial values within the 6% systematic uncertainty dominated by the fiber coupling condition.





Burn-in of 24 MTx modules is shown. Measurements are plotted for the means with RMS errors of the 48 Tx's in time for the power meter readings and the AOP and OMA of eye-diagrams. The dips of eye-diagram values near 4000 hrs is due to fiber defects.

[1] *"ATLAS liquid argon calorimeter Phase-I upgrade technical design report"*, ATLAS-TDR-022, Sep. 20, 2013.
[2] *"ATLAS New Small Wheel Technical Design Report"*, ATLAS-TDR-020, June, 2013.
[3] *"8-Gbps-per-channel radiation-tolerant VCSEL drivers for the LHC detector upgrade"*, JINST 10 C02017 (2015).
[4] *"Component Prototypes Towards a Low-Latency, Small-Form-Factor Optical Link for the ATLAS Liquid Argon Calorimeter Phase-I Trigger Upgrade"*, IEEE Trans. Nucll. Sci. 62 (2015) 250;
"Mid-board miniature dual channel optical transmitter MTx and transceiver MTRx", JINST 11 C03054 (2016).
[5] *"Aging and Environmental Tolerance of an Optical Transmitter for the ATLASPhase-I Upgrade at the LHC"*, Nucl. Instr. and .Meth. A831 (2016) 349.