Opto-system prototypes and preliminary tests for ATLAS ITk Pixel Detector

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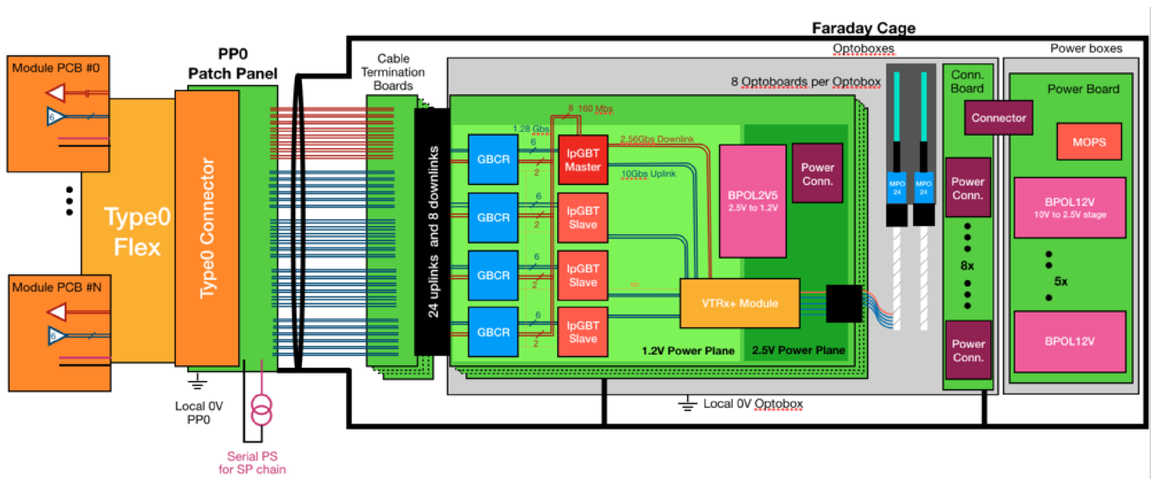
I. Motivation

- A major component of the radiation hard, high speed data transmission in the ATLAS HL-LHC pixel detector is electrical-to-optical conversion
- Preliminary tests performed that validate the concept and design

II. Overview of the ATLAS ITk Pixel Readout Architecture

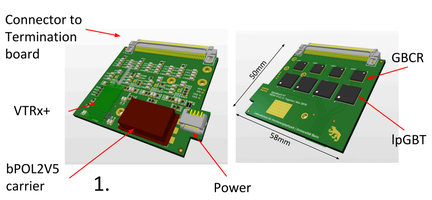


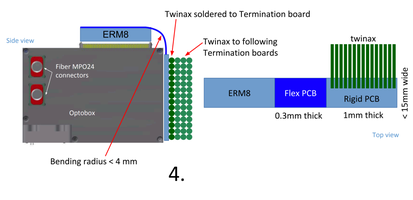
- The electrical data signals received from the front-end chips are converted into optical signals using optoboards and directly routed to the off-detector readout cards through optical fibres
- 24x1.28 Gbps electrical uplinks are serialised into 4x10.24 Gbps optical uplinks
- 2.56 Gbps optical downlinks are deserialised into up to 8x160 Mbps electrical downlinks
- 252 optoboards required for data transmission

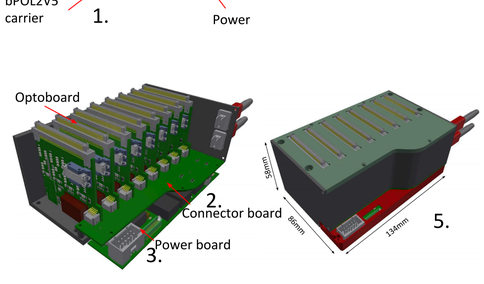
III. The Opto-System

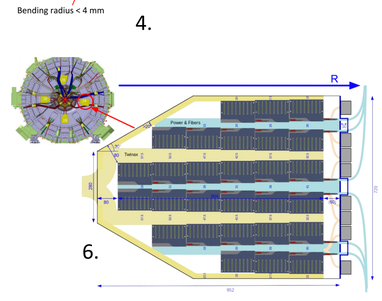
1. Optoboard:
- 1 Optoboard features 4 Gigabit Cable Receivers (GBCRs), 4 low-power Gigabit Transceivers (lpGBTs), 1 Versatile Link Transceiver Plus (VTRx+) module and 1 bPOL2V5 DCDC converter. GBCRs are responsible for equalising the electrical signal from/to the ITk Pixel front-end (FE) chips via twinax cables. The lpGBTs multiplexes/de-multiplexes the high-speed uplinks/downlinks. VTRx+ coverts high-speed signals from electrical to optical and vice-versa

2. Connector board:
- 2.5 V power distribution interface from bPOL12V between a power board and 8 Optoboards









3. Power board:
- Features 5 bPOL12V, DCDC converters for powering of 8 Optoboards and 1 MOPS ASIC to monitor temperature and bPOLs' output voltages

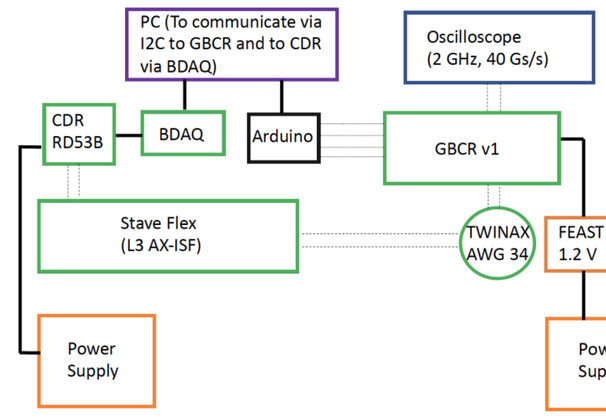
4. Termination board:
- A rigid-flex PCB connecting twinax cables from detector to Optoboard

5. Optobox+Powerbox:
- Mechanical structure containing 8 Optoboards, 1 Connector board + 1 Power board and optical fibres

6. Optopanel:
- Mechanical structure containing Optoboxes, twinax cables, optical fibres, power and CAN cables, and the cooling plate

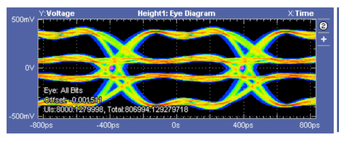
IV. Data Transmission tests up to Optoboard - Jitter Analysis

Jitter gives insight into the root causes of eye closure, bit errors, and observing transmission losses.

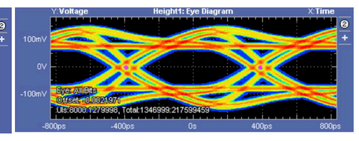


- 1.28 Gbps uplink tested with PRBS15 generated by the CDR chip of the ATLAS ITk FE (RD53B). The 6 m Twinax cable shown here has been irradiated to 92 Mrad
- Signal amplitude reduces by a factor of 4 for 12 dB power loss over twinax cable at 0.64 MHz (data rate 1.28 Gbps). Signal is restored by GBCR. The performance will improve with next GBCR version, designed for the 1.28 Gbps, 1 m flex and up to 6 m twinax cable

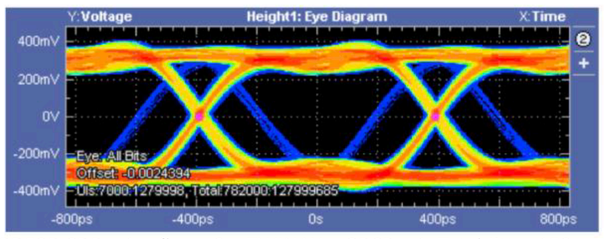
Concept validated: Signal amplitude restored as desired



RD53B CDR with pre-emphasis, Total Jitter 220 ps

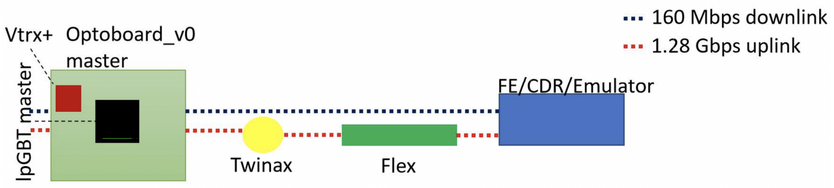


RD53B CDR + 6m TWINAX with pre-emphasis, Total Jitter 240 ps



RD53B CDR + 1m flex + 6m TWINAX + GBCR_v1, Total Jitter 152 ps

V. Preliminary tests with Optoboard prototype - BER Tests



The robustness of the lpGBT master-slave functionality, as envisioned for the ITk Pixel detector and over all signal integrity is checked by Bit Error Rate (BER) Tests.

- Downlink from master lpGBT to RD53B CDR
- Uplink generated by RD53B CDR to master lpGBT or slave lpGBT either directly or via twinax and flex
- Internal lpGBT pattern checker used

Incoming Uplink	BER	Total no. of Bits
lpGBT master	$<1.4\text{x}10^{-13}$	$2.2\text{x}10^{13}$
lpGBT slave	$2.7\text{x}10^{-13}$	$2.2\text{x}10^{13}$
lpGBT master via 1 m flex and 6 m unirradiated twinax	$7.9\text{x}10^{-11}$	$4.4\text{x}10^{12}$

Concept validated: Successful configuration and communication of lpGBT master using optical downlink, and of 3 lpGBT slaves using I2C. And GBCR in uplink will ensure that BER $< 10^{-12}$ specifications are met

VI. Next Steps

- Testing of high speed optical links along with electrical links over the entire chain using pattern generator and checker in the FPGA board
- Optoboard_v1 and GBCR_v2 are available and await testing in a more realistic setup as envisioned for ITk Pixel detector

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