Test bench Development for the Radiation Hard GBTX ASIC

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Introduction – GBTX ASIC in the GBT Project

The GBT Project has developed radiation hard ASICs to implement bidirectional optical links between the on detector and off detector electronics for the future LHC upgrades. The GBTX ASIC transceiver acts as an interface between the front-end electronics and the optical link, featuring:

- Radiation hard design
- 4.8 Gb/s optical link with optional forward error correction or 8b10b encoding
- Transceiver, receiver or transmitter mode based on LHC clock recovered from data
- Up to 40 e-links programmable at 80, 160 or 320 Mb/s data rate plus a 80 Mb/s control e-link
- Up to 40 e-link clocks programmable at 40, 80, 160 or 320 MHz for clock distribution
- 8 phase/frequency-programmable SLVS clock outputs at 40, 80, 160 or 320 MHz with 50 ps phase resolution

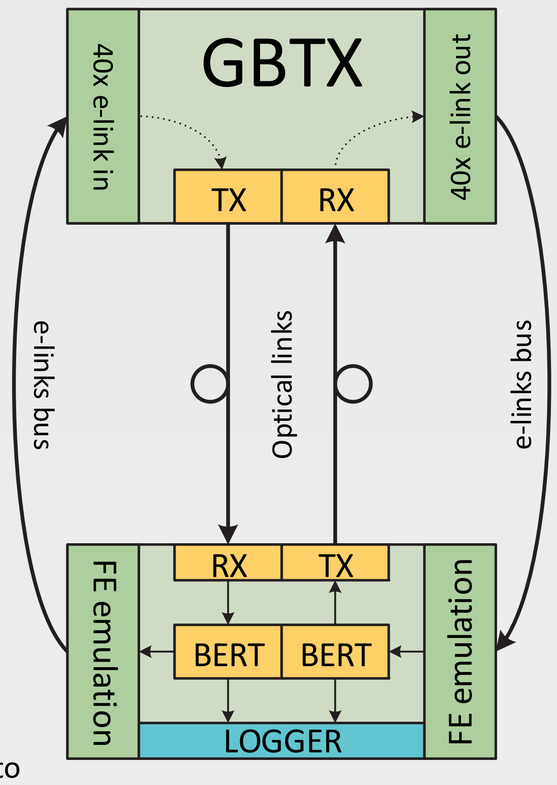
GBTX ASIC with crystal

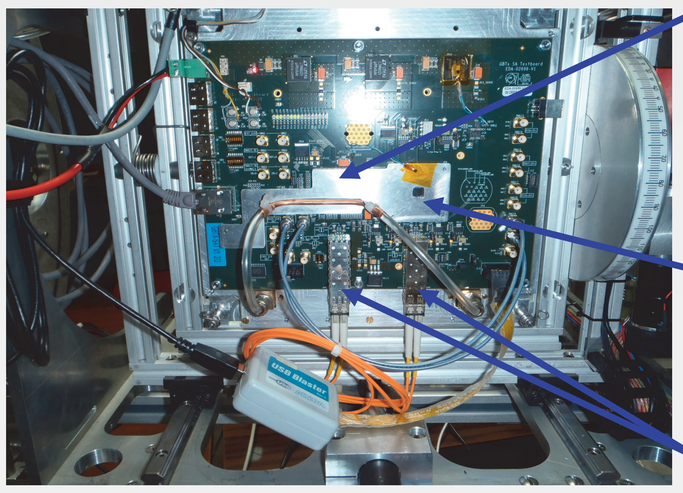
Stand-Alone test board

The test bench consists of a custom-design PCB, called Stand-Alone Test board (SAT board), which allows bidirectional Bit Error Rate (BER) tests on the GBTX using full payload. To do so, the SAT board hosts the GBTX, 2x SFP+ sockets compatible with VTRX transceivers, an Ethernet connection and an Altera Cyclone V GT FPGA for full GBTX control, including:

- Full control over GBTX registers through the optical link or I^2C and configuration pins
- Backend emulation using the GBT-FPGA firmware
- Frontend emulation at all data rates with fine clock deskewing for FPGA's e-link inputs
- Bidirectional 2^{16} Pseudo Random Bit Sequence BER tests
- BER test logging of frame errors, lock errors and configuration errors

The SAT board is controlled with a Graphical User Interface over Ethernet (Ref. S. Feger, *A software Package for the full GBT Chipset Lifecycle)*





SAT board with water-cooling heat-sink inside the vacuum chamber before SEU testing (Louvain-la-Neuve, Feb. 2014)

Radiation test campaigns

Two irradiation campaigns were carried out to characterize the GBTX under a radiation environment. The tests performed were:

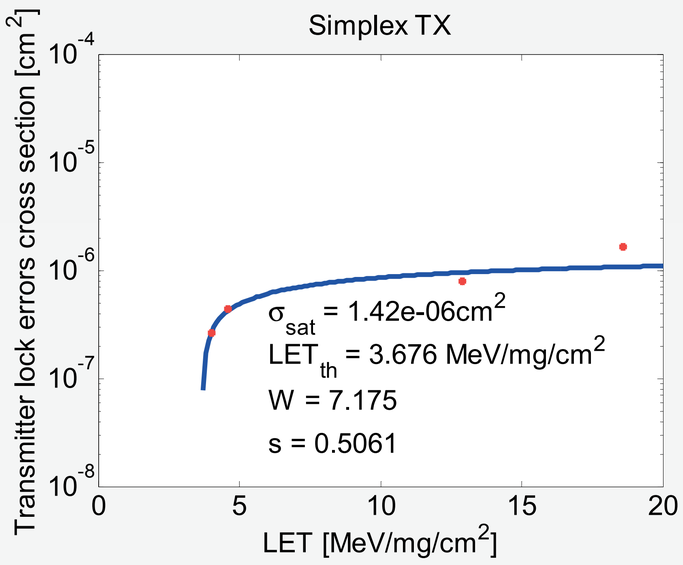
- Total Ionizing Dose (TID) testing, CERN, Dec. 2013
  - X-rays (100 krad/min) up to 100 Mrad
  - GBTX remained fully functional with <10% total jitter increase
- Single Event Upsets (SEU) testing, Louvain-la-Neuve, Belgium, Feb. 2014
  - Performed in the Heavy Ion Irradiation Facility with high penetration particles (Ne, Ar, Ni and Kr) with different angles (0º, 30º, 45º and 60º)
  - GBTX set in receiver and transmitter modes with e-links at 80 and 160 Mb/s data rates
  - Performed full payload BER tests, while monitoring frame errors, lock errors and registers configuration errors

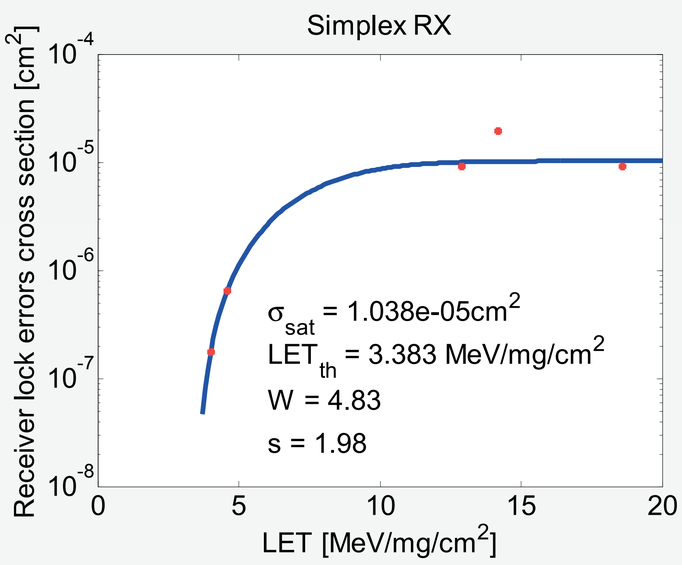
SEU Results

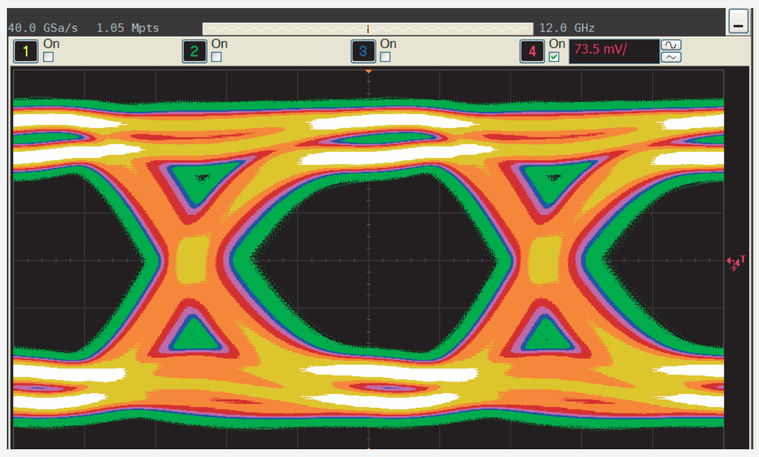
- Table shows an estimate of the error rates calculated for different positions in the CMS detector in the current LHC environment using an 160 Mb/s e-link data rate (Errors/(device·day))
- For the LHC upgrades these numbers need to be multiplied by a factor of 5 to 10
- SEUs provoked different types of errors:
  - TX frame errors → few bit errors per frame
  - RX lock errors (~68 % of the TX frame error rate) → burst of wrong frames
  - TX lock errors (~14 % of the TX frame error rate) → burst of wrong frames
  - RX frame errors (~10% of the RX lock error rate) → few bit errors per frame
  - Configuration errors (no errors observed below 12.9 MeV/mg/cm²)

Detector position	Flux (p/cm²·s)	Lock errors		Frame errors	
		RX	TX	RX	TX
Exp. Hall	8.50E+01	2.5E-05	4.9E-06	-	3.6E-05
Outer Tracker	1.50E+05	5.5E-02	1.0E-02	-	7.0E-02
Endcap ECAL	2.98E+05	0.1	2.2E-02	-	0.2
Pixel	1.40E+07	7.8	1.4	-	10.0

Error rate estimates based on:
M. Huhtinen, and F. Faccio, *"Computational method to estimate Single Event Upset rates in an accelerator environment"*
http://www.sciencedirect.com/science/article/pii/S0168900200001558







GBTX TX eye after TID testing; TJ = 85.28 ps (+7.7% pre-rad)
$RJ_{(rms,narrow)}$ = 2.65 ps (-4.9 % pre-rad)

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