Neutron Irradiation Tests in Oxford

Readout Electronics Production Readiness Review

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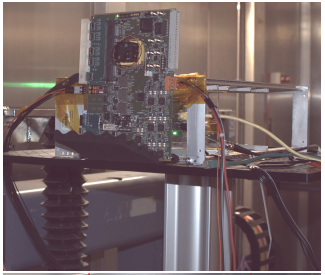
Executive Summary

- Irradiation of board with Neutron beam
- Accumulated Fluence: $\approx 5 \times 10^{11}\,\mathrm{n/cm^2}$ ($\hat{=}$ 30 days of ITS operation)
  - $3.1 \times 10^{11}\,\mathrm{n/cm^2}$ ($\hat{=}$ 18 days ITS) pure Ultrascale data taking
- Main area of beam: Ultrascale FPGA, ProASIC3 FPGA, Configuration Flash
- Results comparable to beam tests in Prague
- No significant change of upset rate due to PA3 irradiation
- No unexpected failure types observed

Readout Chain tested and working as expected while irradiating major components of RUv1.

Setup

- RUv1 in beam
- Beam centered between PA3, US and Flash
- Inner Barrel Stave out of beam
- Main test with beam in shown position
- Short test runs at different positions
  - PA3 covered
  - Flash covered (beam shielded)



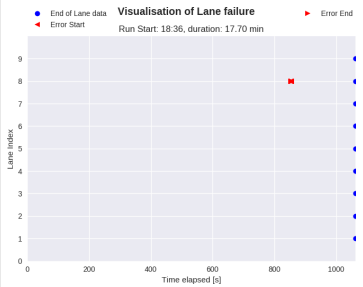
Test Summary

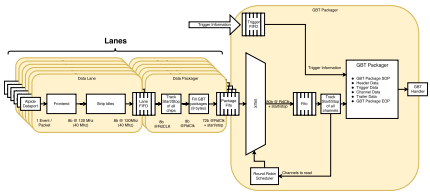
- Average time for a run: 20 min
- Ultrascale design fails as expected
  - Readout failures
  - Few instances of slow control or wishbone failures
  - Radiation monitor mismatches
- PA3 failures as expected
  - Failed to program RUv1
  - CRC mismatches during scrubbing
  - Soft reset fixes stuck PA3
- No corruption of flash configuration (image + scrubbing file)
- Recorded 1 instance of power glitch

Readout Error Classification

Lane Error

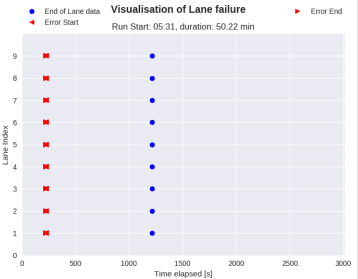
- Single Lane Error
- Recovered by Scrubbing





GBT Error

- Multiple Lane Errors
- Data Reception stops
- Still stuck after scrubbing

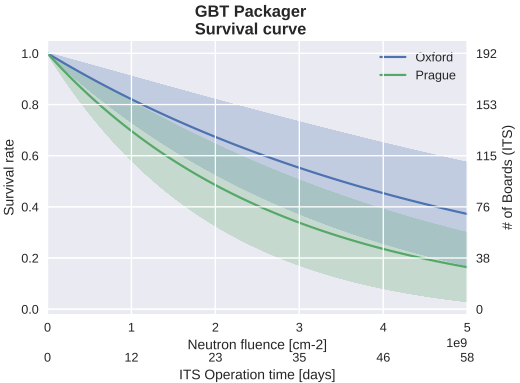


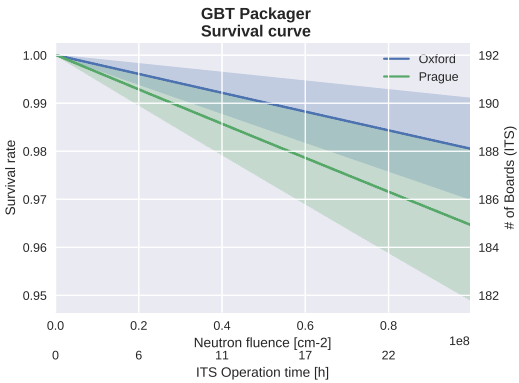
Main Run: Error Rates

Accumulated Fluence: $\approx 6.5 \times 10^{10}\,\mathrm{n/cm^2}$

Run	Part	Mean Fluence To Failure (Time in ITS)	Lower Bound ci=0.95	Upper bound ci=0.95
Main	Lane	$7.4 \times 10^{10}\,\mathrm{n/cm^2}$	$6.3 \times 10^{10}\,\mathrm{n/cm^2}$	$8.8 \times 10^{10}\,\mathrm{n/cm^2}$
(Full IB)		47.7 h	40.6 h	56.5 h
(Full OB)		6.1 h	5.1 h	7.2 h
(Full ITS)		5.4 h	4.6 h	6.4 h
	GBT	$5.1 \times 10^{9}\,\mathrm{n/cm^2}$	$3.5 \times 10^{9}\,\mathrm{n/cm^2}$	$9.2 \times 10^{9}\,\mathrm{n/cm^2}$
(Full IB)		29.2 h	20.0 h	52.0 h
(Full OB)		9.7 h	6.6 h	17.3 h
(Full ITS)		7.3 h	5.0 h	1.3×10^{1} h

Comparison with Prague Testbeam



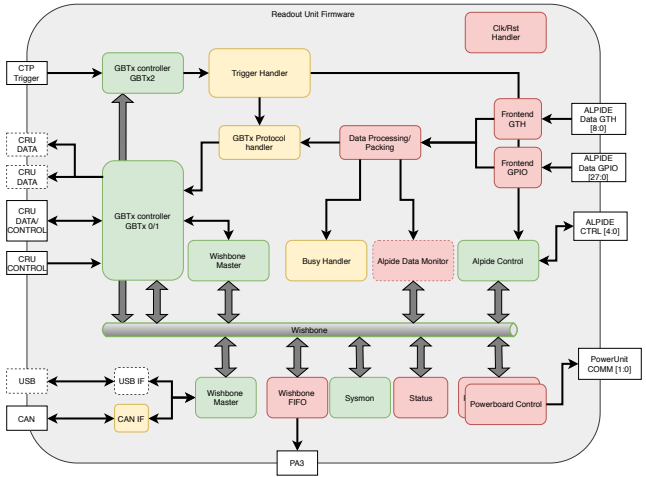


Observed Power Glitch

- One instance of a Powerglitch observed
- Run failed due to SCA communication error
- No communication with SCA during cleanup routine
- Following run starts without issues (No powercycle, no reset of PA3)

Backup Slides

Firmware Overview



US Observations

- Datapath
  - $\approx$ 15 instances of readout failing and not recovering
  - several instances of Lane data not being forwarded (possible cause: Lane RR arbiter stuck)
  - several instances of GBT data not being forwarded (possible cause: trigger_handler)
  - 1 instance of data errors which are not recovered
    - internal event data check still ok -¿ error further downstream
- Monitors / Counters
  - Wishbone errors (causing stop of run)
  - incorrect readouts (value spiking for 1 readout, backto normal for next read)
  - Radiation monitor mismatches

PA3 Observations

- Fail to reprogram Ultrascale
  - Frequency: $\approx$ 10 times during whole testbeam
  - Solved by resetting PA3
- Scrubbing counter not increasing (TODO: Crosscheck Error rate on US)
  - Frequency: $\approx$ 5 times during whole testbeam
  - Solved by resetting PA3
- Upsets in CRC check
  - calculated CRC changes for single read
  - Back to expected value for next read (no intervention required)
  - Frequency: $\approx 10/h$
  - No effect on US firmware

Observed Power Glitch

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- Run failed due to SCA communication error
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- Following run starts without issues (No powercycle, no reset of PA3)

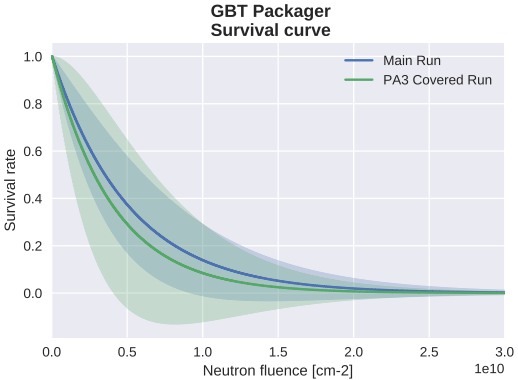
Runs

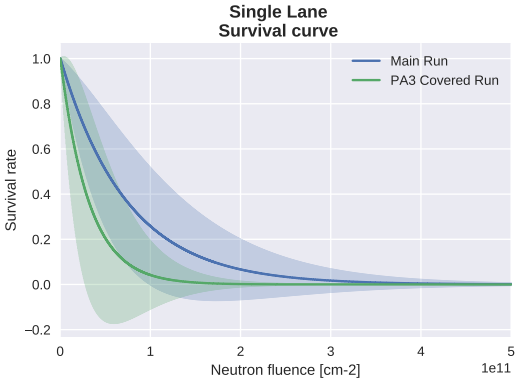
- Monday Parasitic Run
  - Various changes in beam size (colimeter), center position
- Monday Night/ Tuesday Parasitic Run
  - Beam down over night
- Tuesday Parasitic Run
  - Colimeter opened to 100x100mm, Table moved to put RU in center
- Wednesday Parasitic Run
  - Colimeter fully open. Table moved around, Flux changing for RU.
- Main Run
- PA3 Covered Run (PA3 covered from Beam)
- Flash Covered Run
- Wednesday night Parasitic Run

Comparison with Prague Testbeam in Numbers

Run	Part	Mean Fluence To Failure (Time in ITS)	Lower Bound ci=0.95	Upper bound ci=0.95
Oxford	Lane	$7.4 \times 10^{10}\,\mathrm{n/cm^2}$	$6.3 \times 10^{10}\,\mathrm{n/cm^2}$	$8.8 \times 10^{10}\,\mathrm{n/cm^2}$
(Full ITS)		5.4 h	4.6 h	6.4 h
	GBT	$5.1 \times 10^{9}\,\mathrm{n/cm^2}$	$3.5 \times 10^{9}\,\mathrm{n/cm^2}$	$9.2 \times 10^{9}\,\mathrm{n/cm^2}$
(Full ITS)		7.3 h	5.0 h	1.3×10^{1} h
Prague	Lane	$3.5 \times 10^{10}\,\mathrm{n/cm^2}$	$3.2 \times 10^{10}\,\mathrm{n/cm^2}$	$3.9 \times 10^{10}\,\mathrm{n/cm^2}$
(Full ITS)		2.6 h	2.3 h	2.8 h
	Gbt	$2.8 \times 10^{9}\,\mathrm{n/cm^2}$	$2.2 \times 10^{9}\,\mathrm{n/cm^2}$	$3.8 \times 10^{9}\,\mathrm{n/cm^2}$
(Full ITS)		4.0 h	3.2 h	5.4 h

Main Run vs PA3 covered: Error Rates





Main Run vs PA3 covered: Error Rates in Numbers

Run	Part	Mean Fluence To Failure (Time in ITS)	Lower Bound ci=0.95	Upper bound ci=0.95
Main	Lane	$7.4 \times 10^{10}\,\mathrm{n/cm^2}$	$6.3 \times 10^{10}\,\mathrm{n/cm^2}$	$8.8 \times 10^{10}\,\mathrm{n/cm^2}$
(Full ITS)		5.4 h	4.6 h	6.4 h
	GBT	$5.1 \times 10^{9}\,\mathrm{n/cm^2}$	$3.5 \times 10^{9}\,\mathrm{n/cm^2}$	$9.2 \times 10^{9}\,\mathrm{n/cm^2}$
(Full ITS)		7.3 h	5.0 h	1.3×10^{1} h
PA3 Covered	Lane	$3.1 \times 10^{10}\,\mathrm{n/cm^2}$	$2.4 \times 10^{10}\,\mathrm{n/cm^2}$	$4.6 \times 10^{10}\,\mathrm{n/cm^2}$
(Full ITS)		2.3 h	1.7 h	3.3 h
	GBT	$4.0 \times 10^{9}\,\mathrm{n/cm^2}$	$2.2 \times 10^{9}\,\mathrm{n/cm^2}$	$2.0 \times 10^{10}\,\mathrm{n/cm^2}$
(Full ITS)		5.8 h	3.2 h	2.9×10^{1} h

Error Rates, All Runs (1)

Run	Part	Mean Fluence To Failure (Time in ITS)	Lower Bound ci=0.95	Upper bound ci=0.95
Mon Parasitic Run	Lane	$1.7 \times 10^{11}\,\mathrm{n/cm^2}$	$1.4 \times 10^{11}\,\mathrm{n/cm^2}$	$2.2 \times 10^{11}\,\mathrm{n/cm^2}$
(Full ITS)		12.2 h	9.9 h	15.8 h
	Gbt	$9.3 \times 10^{9}\,\mathrm{n/cm^2}$	$5.5 \times 10^{9}\,\mathrm{n/cm^2}$	$3.0 \times 10^{10}\,\mathrm{n/cm^2}$
(Full ITS)		13.5 h	8.0 h	43.9 h
Mon Night Parasitic Run	Lane	$7.0 \times 10^{10}\,\mathrm{n/cm^2}$	$5.6 \times 10^{10}\,\mathrm{n/cm^2}$	$9.2 \times 10^{10}\,\mathrm{n/cm^2}$
(Full ITS)		5.1 h	4.1 h	6.7 h
	Gbt	$5.8 \times 10^{9}\,\mathrm{n/cm^2}$	$3.4 \times 10^{9}\,\mathrm{n/cm^2}$	$2.3 \times 10^{10}\,\mathrm{n/cm^2}$
(Full ITS)		8.5 h	4.9 h	32.6 h
Tuesday Parasitic Run	Lane	$1.0 \times 10^{11}\,\mathrm{n/cm^2}$	$9.1 \times 10^{10}\,\mathrm{n/cm^2}$	$1.1 \times 10^{11}\,\mathrm{n/cm^2}$
(Full ITS)		7.3 h	6.7 h	8.2 h
	Gbt	$8.3 \times 10^{9}\,\mathrm{n/cm^2}$	$6.4 \times 10^{9}\,\mathrm{n/cm^2}$	$1.2 \times 10^{10}\,\mathrm{n/cm^2}$
(Full ITS)		12.0 h	9.2 h	17.2 h
Wednesday Parasitic Run	Lane	$2.1 \times 10^{10}\,\mathrm{n/cm^2}$	$1.5 \times 10^{10}\,\mathrm{n/cm^2}$	$3.9 \times 10^{10}\,\mathrm{n/cm^2}$
(Full ITS)		1.6 h	1.1 h	2.8 h
	Gbt	$2.4 \times 10^{9}\,\mathrm{n/cm^2}$	$1.0 \times 10^{9}\,\mathrm{n/cm^2}$	$-6.2 \times 10^{9}\,\mathrm{n/cm^2}$
(Full ITS)		3.4 h	1.4 h	−8.9 h

Error Rates, All Runs (2)

Run	Part	Mean Fluence To Failure (Time in ITS)	Lower Bound ci=0.95	Upper bound ci=0.95
Main Run	Lane	7.4×10^{10} n/cm^2	6.3×10^{10} n/cm^2	8.8×10^{10} n/cm^2
(Full ITS)		5.4 h	4.6 h	6.4 h
	Gbt	5.1×10^{9} n/cm^2	3.5×10^{9} n/cm^2	9.2×10^{9} n/cm^2
(Full ITS)		7.3 h	5.0 h	13.3 h
PA3 Covered Run	Lane	3.1×10^{10} n/cm^2	2.4×10^{10} n/cm^2	4.6×10^{10} n/cm^2
(Full ITS)		2.3 h	1.7 h	3.3 h
	Gbt	4.0×10^{9} n/cm^2	2.2×10^{9} n/cm^2	2.0×10^{10} n/cm^2
(Full ITS)		5.8 h	3.2 h	29.3 h
Flash Covered Run	Lane	1.4×10^{11} n/cm^2	1.1×10^{11} n/cm^2	2.0×10^{11} n/cm^2
(Full ITS)		10.5 h	8.2 h	14.8 h
	Gbt	-	-	-
(Full ITS)		-	-	-
Wed Night Parasitic Run	Lane	9.4×10^{10} n/cm^2	7.8×10^{10} n/cm^2	1.2×10^{11} n/cm^2
(Full ITS)		6.9 h	5.7 h	8.6 h
	Gbt	6.7×10^{9} n/cm^2	4.3×10^{9} n/cm^2	1.5×10^{10} n/cm^2
(Full ITS)		9.7 h	6.3 h	21.2 h