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ATLAS Collaboration

Irradiation Studies of Gb/s Optical Links Developed for the Front-end Read-out of the ATLAS Liquid Argon Calorimeter

Topics :

- Link architecture
- A Gb/s demonstrator link
- Irradiation studies
  - Packaged VCSEL's (Vertical Cavity Surface Emitting Laser diodes)
  - Multimode optical fibres
  - Gb/s Demonstrator link

The ATLAS LArg Optical link TEAM !

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Link architecture

- Approximately 1500 optical links to transfer data from the electronics boards mounted on detector $\Rightarrow$ data acquisition electronics (up to 200 m away)
- Unidirectional + transmitter on detector
- 32 bit @ 40 MHz $\Rightarrow$ 1.28 Gb/s
- Bit Error Rate(BER) better than 10^{-9}

A key issue is the radiation hardness of the components that will equip the emitting end of the link :

- neutron and gamma radiation
- poor accessibility into ATLAS

$\Rightarrow$ they must operate for 10 years of LHC running

Integrated over 10 years components will be exposed to a high level of neutron 1.7×10^{13}n (1 MeV Si) cm^{-2} and gamma 800 Gy radiation

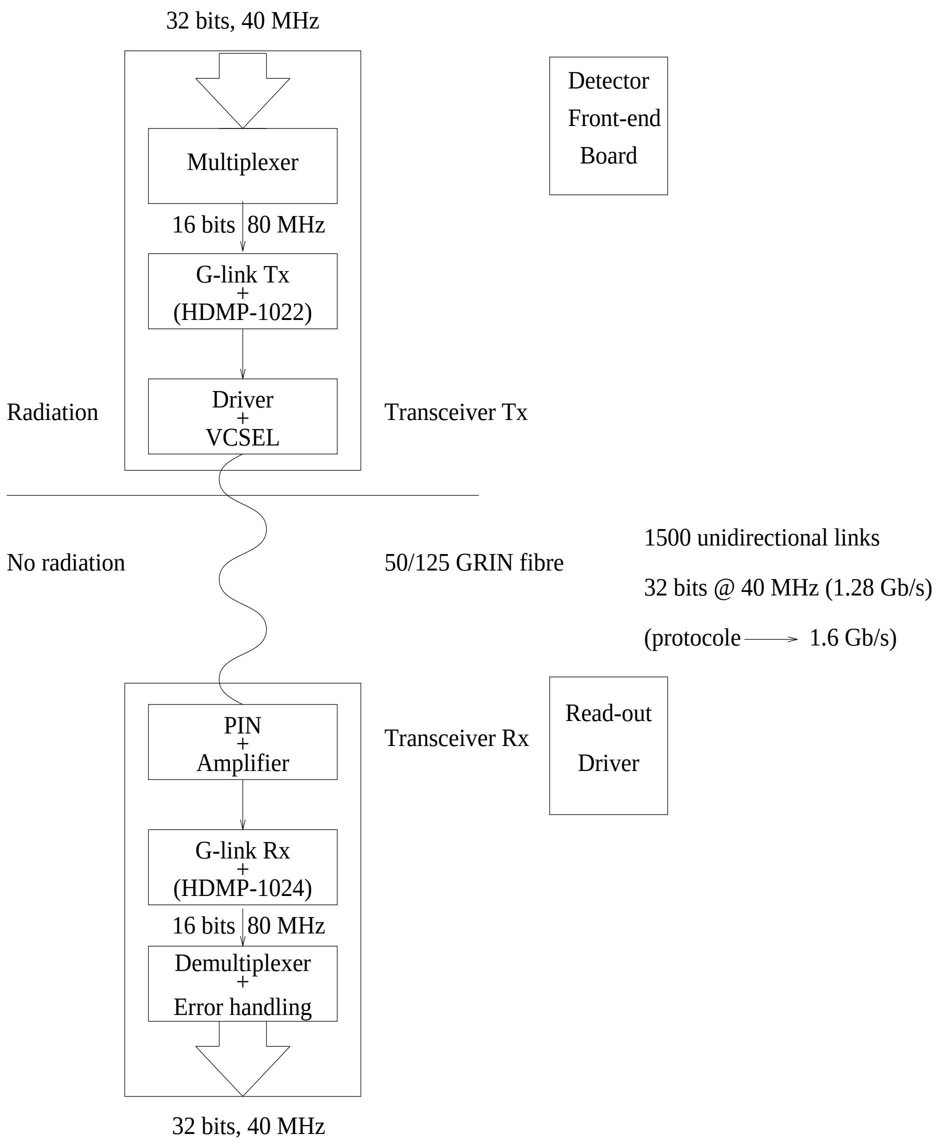
No significant level of radiation is expected on the receiving end of the link

The currently favoured solution is a serial architecture based around commercial 'off-the-shelf' components :

- **G-link chip set manufactured by Hewlett-Packard**
- **Gigabit transceiver modules for optics**
- **multimode GRaded INdex (GRIN) 50/125 fibres**

⇒ Development of a Gb/s demonstrator link

A Gb/s demonstrator link



G-link chipset :

- operated in double frame mode : the addition of external (de)multiplexing elements permits 32 bit data words to be sent as two 20 (16 + a 4 bit control word) bit separate segments
- provides inbuilt error detection and linkdown monitoring through the addition of a 4 bit control field to the 16 bit data word
- data input = TTL
- serial Gb/s output = PECL ⇒ to be connected to standard transceivers

Transceiver modules :

- transmitter : driver circuit + a 850 nm VCSEL
- receiver : PIN photodiode + preamp assembly
- transmitter + receiver can be coupled to a optical cable through a SC connector

Independent transmitter and receiver functions are combined in a single module housing ⇒ not optimal for ATLAS, BUT :

- convenient way of testing realistic components
- development underway to use VCSEL directly driven by G-link transmitter instead of transceiver modules

With no radiation present, the demonstrator link has been tested successfuly for several days !

How does the link perform when irradiated ?

Radiation facilities

Neutron :

- SARA (ISN-Grenoble)$\Rightarrow$ 6 MeV neutrons from a 5 μA beam of 20 MeV deuterons hitting a Be-target
- Dosimetry : Ni foils $\Rightarrow$ neutron fluence measured with an accuracy of $\simeq$ 15 %

Gamma :

- ^{60}Co source : 2 gamma rays 1.17 MeV and 1.33 MeV
- Dose rate :
  - Karolinska (Hospital in Stockholm) : 80 Gyh^{-1}
  - Brookhaven National Laboratory : 200 Gyh^{-1}
- Dosimetry : polymer analine dosimeters $\Rightarrow$ gamma ray doses measured with an accuracy of $\simeq$ 4 %

All the facilities have permitted to measure on-line the performance of candidate optoelectronic components

Radiation studies of packaged VCSEL's

Overview

- 9 Honeywell HFE4080 ST housed VCSELs (with lens)
- 9 Mitel 1A440 ST housed VCSELs (flat window)
- DC mode tests only
- Neutron/gamma radiation tests + annealing studies

Testing procedure :

$\Rightarrow$ Measurement of the light ouput

- VCSEL's stepped through in 20 steps from 0 - 10 mA at the start of a data taking run
- VCSEL's biased above lasing threshold with a DC current when not stepped

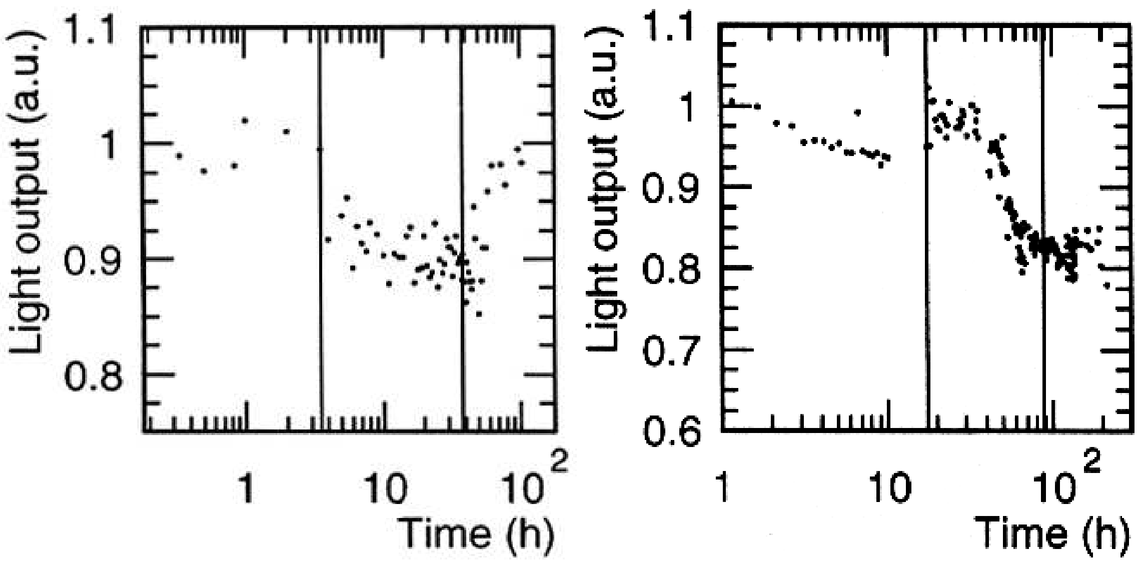
(VCSEL's kept biased during annealing studies)

Radiation studies of packaged VCSEL's

- Total dose :
  - Neutron : $(2.0 \pm 0.4)\,10^{13}$ n (1 MeV Si) cm^{-2} (10 years of LHC running)
  - Gamma : 5.1 ± 0.2 kGy (66 years of LHC running)

- During both irradiations : no change in the threshold current

- Neutron radiation : VCSEL's recovered the pre-irradiation light levels $\neq$ Gamma radiation : no such annealing was observed

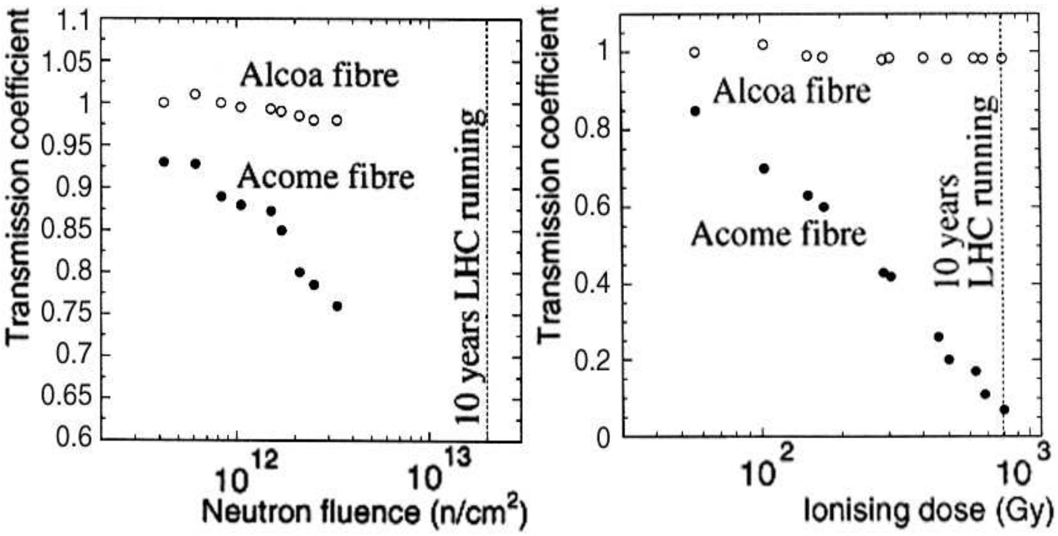


Neutron / Gamma

Multimode optical fibres

$\simeq$ 10 m of optical fibres to be exposed to radiation in ATLAS $\Rightarrow$ neutron and gamma radiation tests of 2 commercial 'off the shelf' fibres:

- 2 multimode 50 / 125 graded index fibres :
  - 8-way ribbon from Acome
  - Duplex cord from Alcoa-Fujikura (transceiver standard)
- strong difference in radiation tolerance :
  - Acome fibre induced attenuation of $\simeq 35\,\%$ after $10^{13}\,\mathrm{n\,cm^{-2}}$ and $90\,\%$ after $800\,\mathrm{Gy}$
  - Alcoa-Fujikura fibre negligible induced attenuation for either type of radiation



Neutron / Gamma

Radiation test of the Gb/s demonstrator link

A set of 4 demonstrator links → neutron flux (only !)
⇒ to measure the radiation tolerance of G-link and ≠ manufactured transceivers

Two different aspects must be investigated :

- total dose studies : the emission part must withstand a 10 years LHC running total neutron fluence
- dose rate studies : the radiation induced bit error rate in the link must be acceptable
  Bit error rate tester (BERT) under construction (not available at the time of irradiation), it will permit to analyse up to 16 (Gigabit/s) links at the same time with pseudo random data flux.
  Commercial BERT for Gb/s links exist BUT they are too expensive + 1 link can be analysed at a time !

Testing procedure

⇒ continuous monitoring of the G-link inbuilt error flags :

- error flag : check of the control field in the transmitted frame
- linkdown flag : the G-link can not identify a frame to lock on

Total dose studies

Total dose studies were made in 3 separate tests :

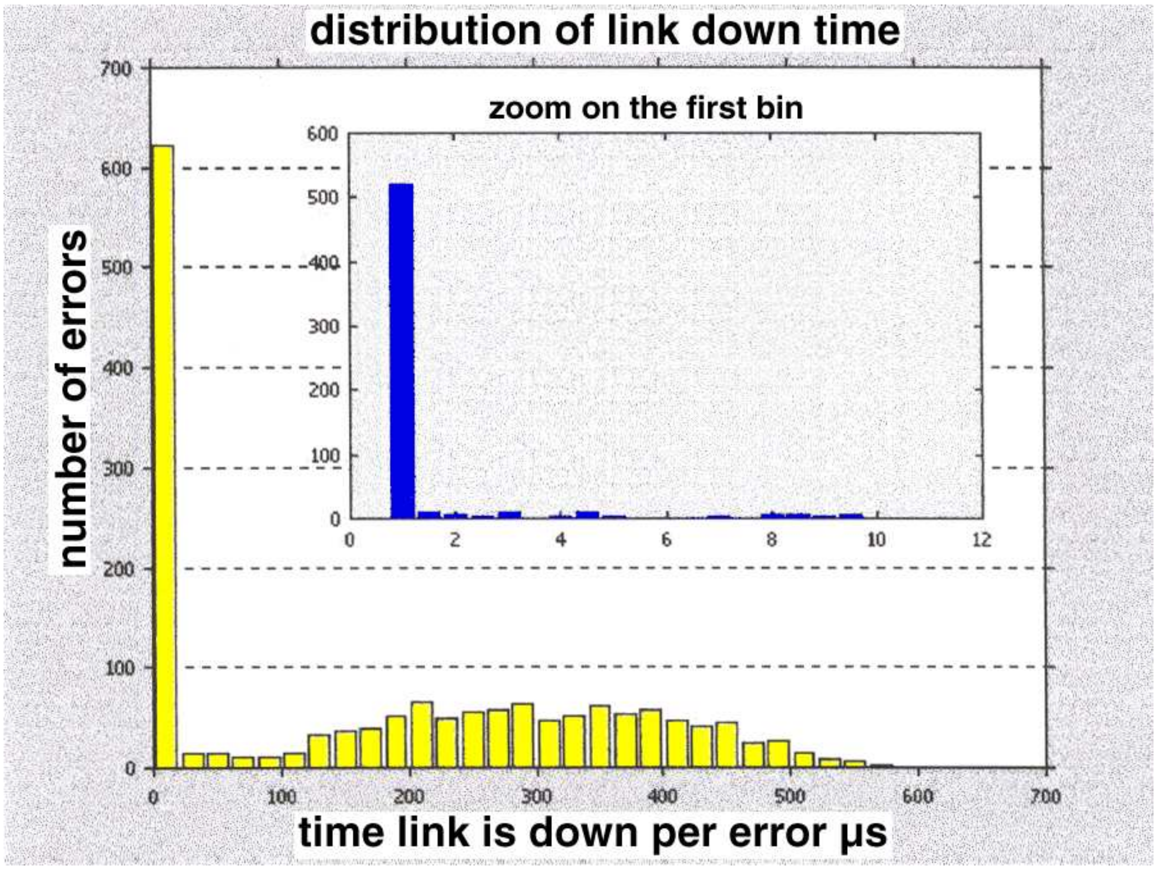
- 2 with optics @ 1.6 Gb/s
- 1 with copper links @ low speed : 160 Mb/s (SARA experimental constraint)

Neutron	G-link	Optics	G-link status	Optics status
10 years LHC	G_1	Honeywell HFM2450	OK	Dead
	G_2	Honeywell HFM2450	OK	Dead
	G_3	Hewlett-Packard	OK	Latch-up
	G_4	Methode MDX-19-4-1	OK	OK
20 years LHC	G_1	copper link	OK	-
	G_2	copper link	OK	-
	G_3	copper link	OK	-
	G_4	copper link	OK	-
10 years LHC	G_1	Methode MDX-19-4-1	OK	OK
	G_5	Methode MDX-19-4-1	OK	OK
	G_6	Methode MDX-19-4-1	OK	OK
	G_7	Methode MDX-19-4-1	OK	OK

Post-irradiation analyses of candidate transceivers :

- Honeywell : driver circuit dead VCSEL OK
- Hewlett-Packard : for technical reason could not be easily tested
- Methode : driver circuit comprised of discrete components

Transient errors studies :



- sharp peak $\Leftrightarrow$ error flag (rate $\simeq$ 1 per minute)
- for time $> 1.6\ \mu s$ $\Leftrightarrow$ linkdown flag (rate $\simeq$ 1.5 per minute)

1 link-down of 300 μs $\Rightarrow$ 24000 frames of 20 bits lost !

BUT SARA neutron flux $\simeq$ 1000 the ATLAS expected one $\Rightarrow$ low dose rate studies necessary to conclude

Dose rate studies

Testing procedure

- 2 experimental difficulties :
  - SARA neutron radiation flux = 1000 times the ATLAS expected one (to make possible total dose analyses)
  - not possible to isolate the G-link from the transceiver since no monitoring would have been possible !

⇒ to cope with these problems :

  - high flux tests were complemented with a reduced intensity neutron flux test
  - a test using copper link (optics removed) has been done @ low speed (SARA experimental constraint ⇒ 15 metres cables to be used)

Observations :

- the rate of the two types of errors drops rapidly with the neutron flux
- G-link and transceiver are both responsible for errors (copper test results)

⇒ a set up in which a specific VCSEL (low threshold lasing current) to be driven directly by G-link would be instructive

SUMMARY AND PROSPECTS

- A serial 1.6 Gb/s demonstrator link has been built based around G-link chipset and commercial VC-SEL/PIN diodes transceiver units
- it satisfies the ATLAS read-out requirements
- it runs error free when no radiation present
- if equiped with Methode transceivers it satisfies the neutron total dose requirements
- the impact of transient errors on data collection must be further investigated
- radiation tolerance of standard VCSEL's have been demonstrated and one of the fibres would be suitable for use in the complete link
- a set up in which a specific VCSEL (low threshold lasing current) to be driven directly by G-link is to be done
- a BERT would be available soon for future ATLAS-like neutron doses studies