Radiation tolerant developments in Beam instrumentation

T. Lefevre on behalf of the Beam instrumentation group

Outline

- Introduction
- BI rad-tolerant developments
- Common developments with EP/ESE
- Testing of rad-tolerant and COTS components

General BI considerations

- Most of BI activities are subject to R2E issues
  - Typical implementation of BI acquisition system
    - Front-End (FE) electronic in the Tunnel – Back-End (BE) electronic on Surface
    - FE based on rad-hard / rad-tolerant electronics
    - True for all large BI systems: BPM and BLM in SPS and LHC
    - Typical budget split between FE/BE electronics: 50% - 50%

- BI standardization
  - Encouraging common developments and ‘standard’ solution within the group
  - Part of an even larger effort of standardization with the BE-CO group for acquisition system and data transmission links

- Collaboration with EP – BI benefiting from their ASIC design and production

BI developments strongly relies on R2E

- FLUKA simulations for an estimation of expected radiation dose (MCWG)
  - Understand the specific constrains
  - Design the required system architecture

- Identifying and testing of rad-tolerant systems (RADWG)
  - Choice of components (COTS, rad-tolerant, rad-hard)
  - Testing at irradiation facilities for validation
    - IRRAD, CHARM, PSI, SACLAY, …
    - Hiradmat (functional tests)

- Radiation monitoring in the CERN accelerator complex (MCWG)
  - Follow-up and evolution of the radiation doses in the machine

BI activities funded by R2E

- R2E supports the development of BI rad-tolerant /Rad-hard systems
  - Through the funding of Students and Fellows
    - based in BI group
    - based in EP/ESE working on ASIC design or Rad-hard components (optical transmission link)
  - Development of BI custom made rad-tolerant FE electronic board for approved projects (LIU, Hilumi,..)
  - General R&D activities looking into longer term problematic for BI (e.g. radiation-hard camera, …)

- R2E supports the validation and purchase of COTS components

A selection of BI-R2E developments

BI boards using ASICs developed by EP

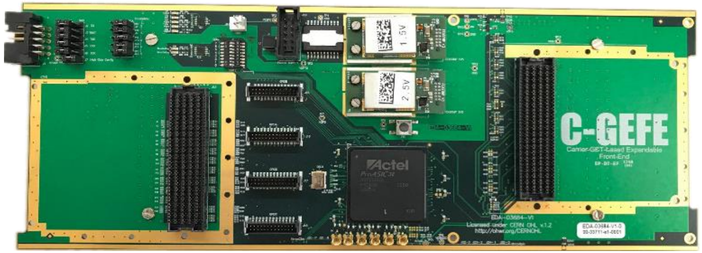
- New digital Front-end board for the SPS beam position acquisition system

  - System installed in tunnel underneath magnet
  - 216 units
  - Part of LIU – Installation performed during LS2

Split GEFE (S-GEFE)

- **FE based on a combination of 2 boards: L-GEFE and F-GEFE**
  - The Link-GEFE (L-GEFE) is rad-hard by design up to TID levels of >10kGy
    - Communication ASIC (GBTx) and optical transceivers (VTRx) from EP
  - The Carrier-GEFE (C-GEFE) is rad-tolerant up to TID levels of 750 Gy
    - FMC carrier card featuring COTS components (e.g. Proasic3 FPGA)
    - FMC mezzanine for applications specific acquisition (e.g. ADCs)

+

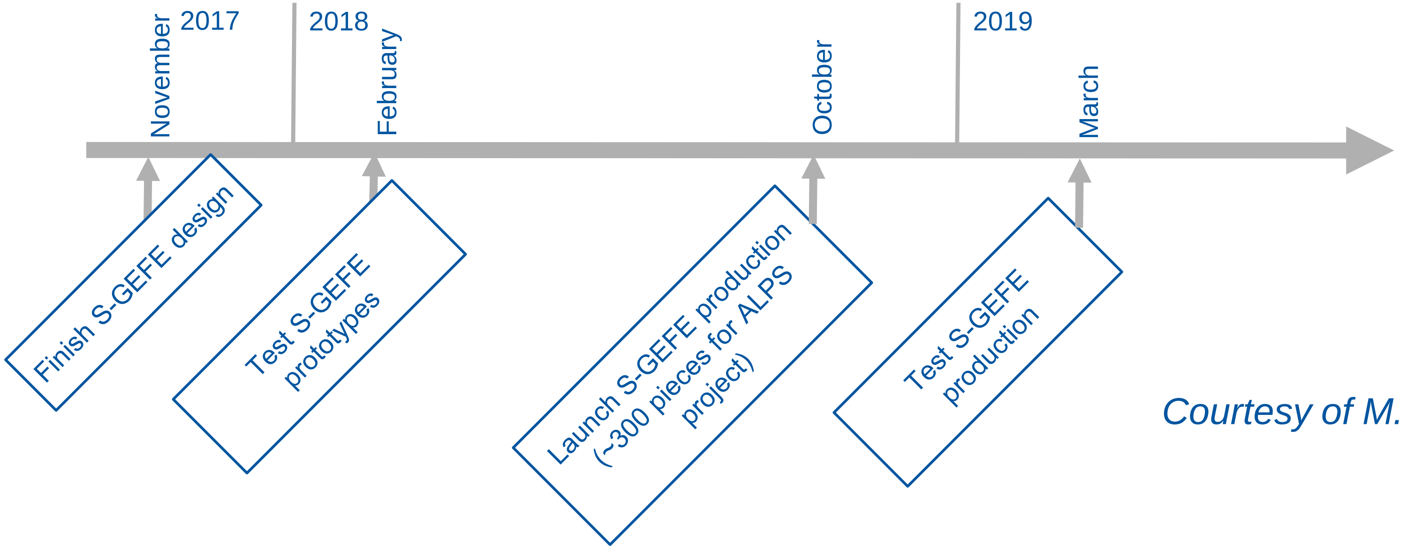


Courtesy of M. Barros Marin

L-GEFE and C-GEFE may be used independently

Split GEFE (S-GEFE)

- **Status:**
  - Production stage (~300 pieces)
- **Roadmap:**



Courtesy of M. Barros Marin

Developments between BI-EP supported by R2E

Common solution for accelerator instrumentation optical links

Developments between BI-EP supported by R2E

<u>Common solution for accelerator instrumentation optical links</u>

- based on the versatile link framework (VTR)
- targeting 10.24 Gb/s upstream operation
- 4 channel wavelength division multiplexing scheme (CWDM)
- compatible with next generation rad-hard chipset for optical data links (LpGBT)

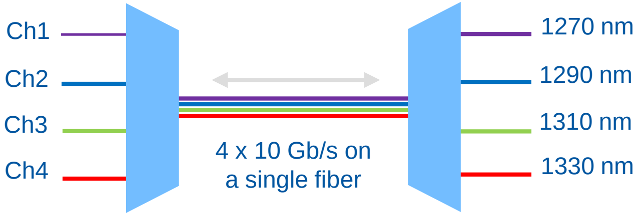
Courtesy of C. Scarcella

Project status

- demonstration of 10.24 Gb/s upstream operation
- Laser driver (GBLD) insensitive to TID in the specification range
- moderate displacement damage of CWDM Lasers

Next steps

- radiation tolerance validation of CWDM optical MUX
- solutions for standard SFP cage compatibility
- defining of final link architecture
- moving towards parts procurement and production



Developments between BI-EP supported by R2E

Common solution for accelerator instrumentation optical links

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- 4 channel wavelength division multiplexing scheme (CWDM)
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See talk on Wednesday afternoon at 17h35 on
'Radiation hardness in single-mode optical links for Accelerator Instrumentation' by Carmelo Scarcella

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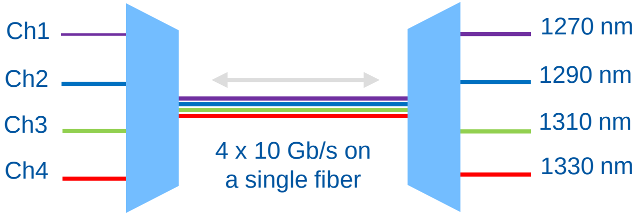


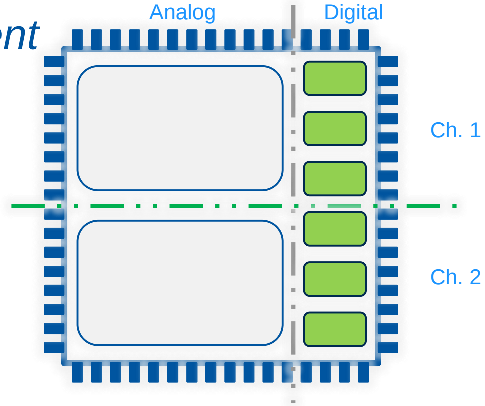
Developments between BI-EP supported by R2E

ASICs development for Beam loss monitoring

Developments between BI-EP supported by R2E

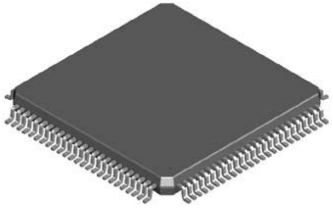
ASICs development for Beam loss monitoring

Developing two fully functional custom ASICs to evaluate the performance of two different architectures within a realistic environment



Technology

- standard CMOS 130 nm qualified at CERN for 200 Mrad
- Supply voltage 1.2 V (possibly higher for analog)
- Two analog readout channels per chip
- Triplicated digital circuitry with majority voting
- Directly compatible with LpGBT (e-Link)
- Double communication channels for redundancy
- Chip dimensions 4x4 mm
- To be housed in a standard 64 pin Quad Flat Package (10x10 mm)



Project schedule:

- 2018 : Design and simulation
- 2019 : Prototypes and testing
- 2020 : Final prototype architecture selection

Courtesy of L. Giangrande

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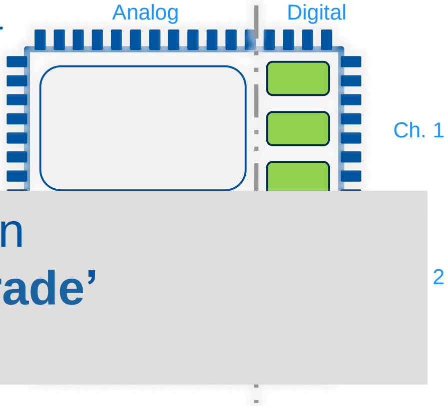
ASICs development for Beam loss monitoring

Developing two fully functional custom ASICs to evaluate the performance of two different architectures within a realistic environment

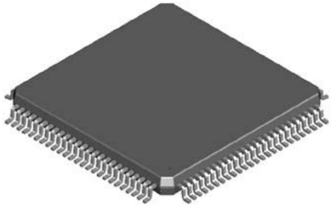


Technology

- standard CMOS 130 nm qualified at CERN for 200 Mrad
- Supply voltage 1.2 V (possibly higher for analog)

See talk on Wednesday afternoon at 17h20 on
'ASIC design for the Beam Loss Monitor upgrade'
by Luca Giangrande

- Double communication channels for redundancy
- Chip dimensions 4x4 mm
- To be housed in a standard 64 pin Quad Flat Package (10x10 mm)



Courtesy of L. Giangrande

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Selecting rad-tolerant components

Selecting rad-tolerant components

NG-Medium Evaluation for BLM

- NanoXplore started in 2015 in Paris
- HW design in Paris and SW design in Montpellier
- STM radhard process
- **Radiation tolerant market** (space and nuclear industries)
- 4 products available or in the roadmap:
  - eFPGA
  - **NG-Medium (65nm)** → VEGAS European project to validate it
  - NG-LARGE (65nm)
  - NG-Ultra (28nm) → DAHLIA European project to create a SoC

➔ Good feedback from the first users (Airbus, Thales, GVM,…):

"really good support and reactivity"

"No major issue on the hardware"

"Huge improvement of the software in 2017-2018"

Courtesy of M. Saccani

Selecting rad-tolerant components

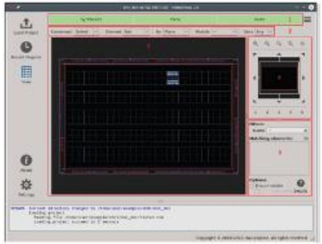
NG-Medium Evaluation for BLM

NG medium

- SRAM FPGA
- RadHardened by design (no need for TMR)
- TID up to 300krad (tested also at CERN)
- ConfigRAM integrity check
- BRAM EDAC
- Packaging: plastic FG625 available
- 35k LUT4/DFF, 112 DSP, 54BRAM, 24 Clocks
- Requires a non-volatile memory for configuration

- EDA: NanoXmap entirely in Python
- This design flow is now mature
- IP core generator and scope debugger available

NG-Medium



NanoXmap

Courtesy of M. Saccani

Selecting rad-tolerant components

NG-Medium Evaluation for BLM

Objective:

- *Replace the antifuse SX72 on the BLM acquisition tunnel board*
- *Improve performances: more bits and faster sampling.*

- *FPGA footprint:*	*PQFP208 (784mm^2)*	➔	*FG625 mm^2*
- *Technology:*	*220nm*	➔	*65nm*
- *Registers:*	*2012*	➔	*32,256*
- *BRAM:*	*0*	➔	*56*
- *DSP:*	*0*	➔	*112*
- *LVDS channels:*	*0*	➔	*240*

Means:

- *One DevKit in use since November in BL section*
  - *Evaluation of the design flow*
  - *Contact with NanoXplore Support to get new features (serial number and internal temperature)*
  - *Design of a mockup by replacing the antifuse pin to pin*

Courtesy of M. Saccani

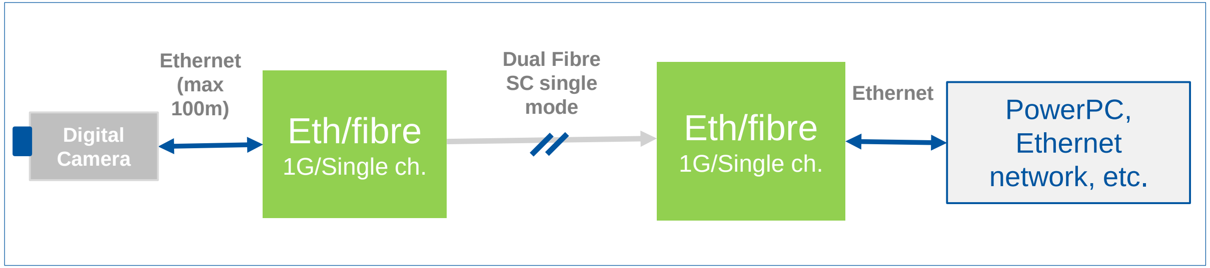
Testing COTS to radiation

Irradiation test of Ethernet to Fibre Optics converter (ADVANTEC EKI-2741LX)

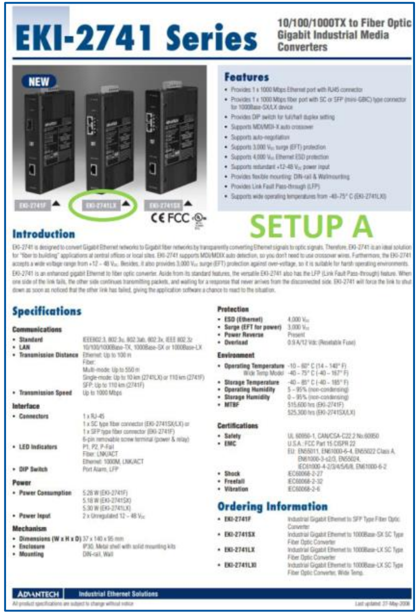
Testing COTS to radiation

Irradiation test of Ethernet to Fibre Optics converter (ADVANTEC EKI-2741LX)

Needed to use high performance Digital camera in CERN accelerator complex



System tested @charm in August 2018



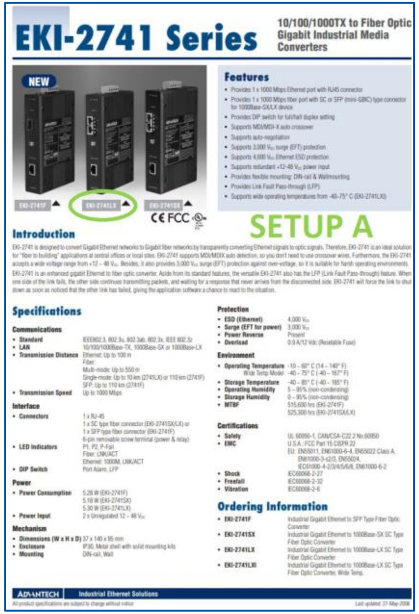
Courtesy of S. Burger

Testing COTS to radiation

Irradiation test of Ethernet to Fibre Optics converter (ADVANTEC EKI-2741LX)

System still alive after the campaigns !

- Single events can stop camera acquisitions
  - Power cycles reset correctly the system
- System keeps working up to 45 Gy TID
  - Shielding for ETH to fiber converters foreseen
- Failure cross section lower than cameras -> Not limiting factor



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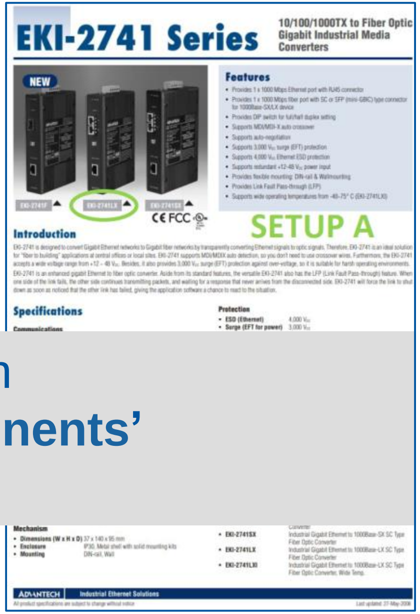


See talk on Wednesday afternoon at 17h50 on
‘Radiation hardness tests of Optical fibre components’
by Damiano Celeste

Courtesy of S. Burger

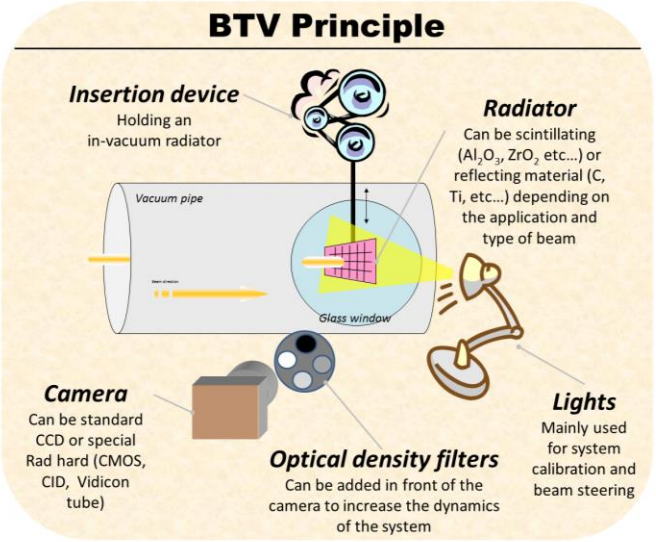
Developing rad-tolerant solutions

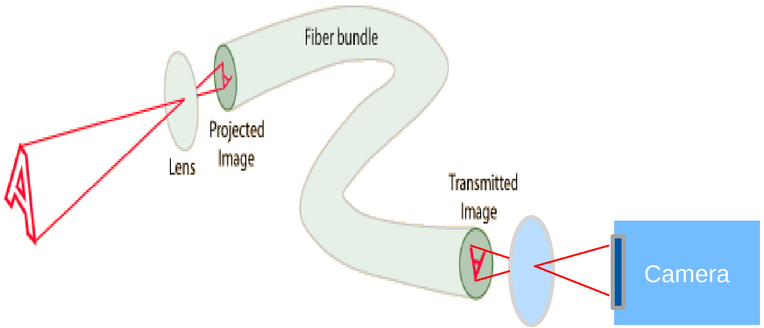
Beam imaging using Optical fibre bundles

Developing rad-tolerant solutions

Beam imaging using Optical fibre bundles

Problem : The most radiation hard cameras used at CERN, i.e. Vidicon tubes, are no longer produced.
Motivation : Moving the camera as far as possible from the source of radiation





Courtesy of D. Celeste

Developing rad-tolerant solutions

Beam imaging using Optical fibre bundles

- Developing optical system using a 10m long Fiber bundle from Fujikura (FIGR10)
- Performing irradiation tests at Saclay using ^{60}Co source
- Performing functional test on a BTV system in TT2 beam line

Courtesy of D. Celeste

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Conclusions

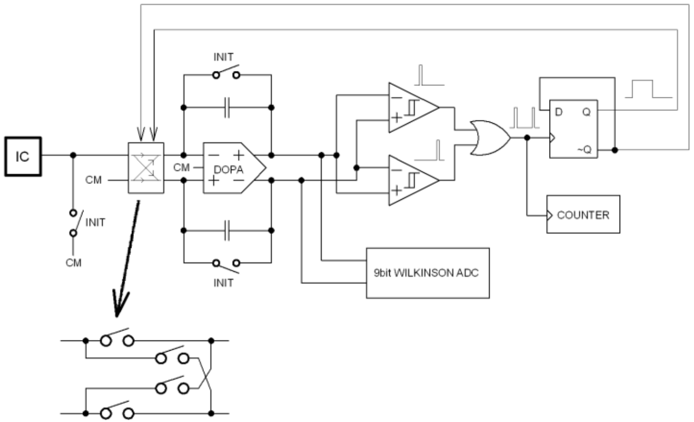
- **R2E is funding projects in BI at a level of 2.5MCHF (CTC in 2025)**
  - Manpower and hardware developments
  - Main CERN projects : LIU, Hilumi and Consolidation
  - R&D activities

- **BI group strongly relies on R2E project structure**
  - Calculations on expected radiation levels and doses to electronic
  - Testing capabilities, especially at CHARM, IRRAD
  - Monitoring capabilities (RadMon)

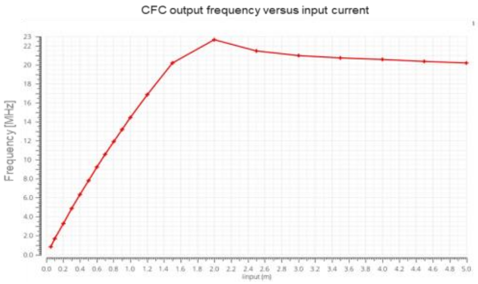
- **Please come and listen to the BI talks tomorrow for more details**

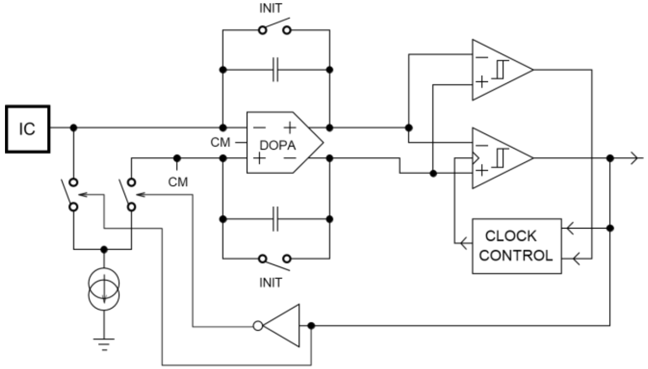
Thanks for your attention

Architectures comparison

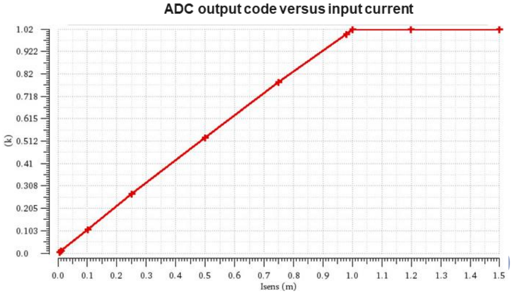


Fast response to large current steps.
INL(before calibration) in the higher range (1pA~1mA): 15 %
INL(before calibration) in the lower range (1pA~10µA): 0.5 %
RMS noise in the 10µs integration window (Wilkinson ADC): < 2 nA
Current consumption: 15 mA

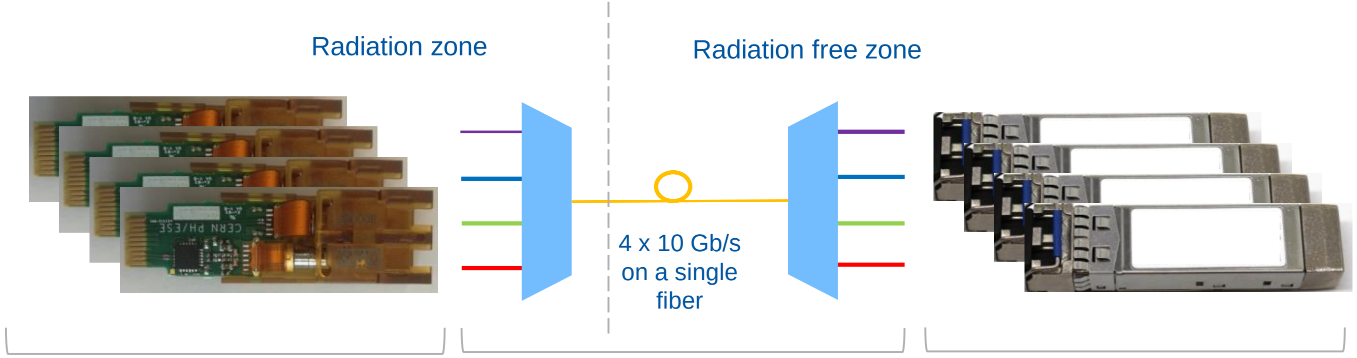




High resolution due to oversampling and numerical filtering.
INL (before calibration) in the range 1µA~1mA: < 2 %
RMS noise in the high current range (before filtering): 250 nA
Current consumption: 4 mA ~ 8 mA



CDWM Single-Mode Versatile link



Front-end
Radiation hard
Transceiver - VTRx

Passive optics
Single-mode optical fibers
Optical MUX/DEMUX

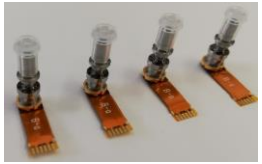
Back-end
Custom off-the-shelf
transceiver

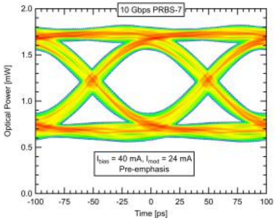
Parameter	Value	Units
Max Uplink Bit Rate	4.8 or 10.24	Gb/s
Max Downlink Bit Rate	4.8	Gb/s
Wavelengths	1270/1290/1310/1330	nm
Total ionizing dose (TID)	10	kGy
Fluence	$5 \cdot 10^{14}$	n/cm^2 MeV neutrons

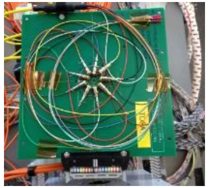
Project Milestones

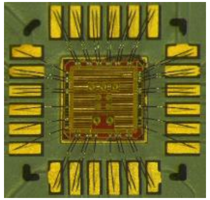
CWDM COTS EEL procurement → 10.24 Gb/s uplink operation → Displacement damage EEL $5 \cdot 10^{14}$ n/cm^2 MeV neutrons fluence → GBLD Laser driver TID test

Progress to date









CWDM MUX radiation tolerance → Standard SFP cage compatibility → Link specs definition and production

Next steps