

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

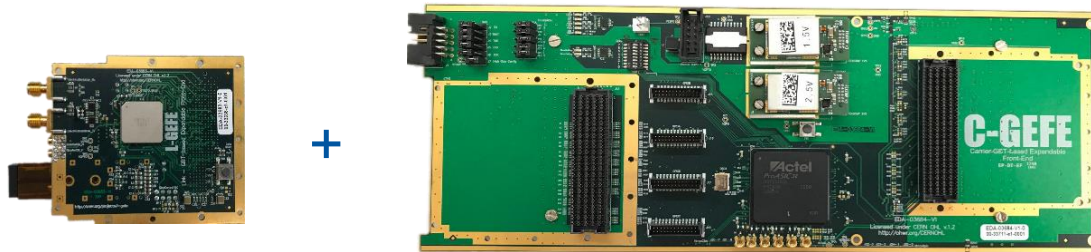
- New **digital Front-end board** for the **SPS** beam position acquisition system



- 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 $>10\text{kGy}$
 - 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)

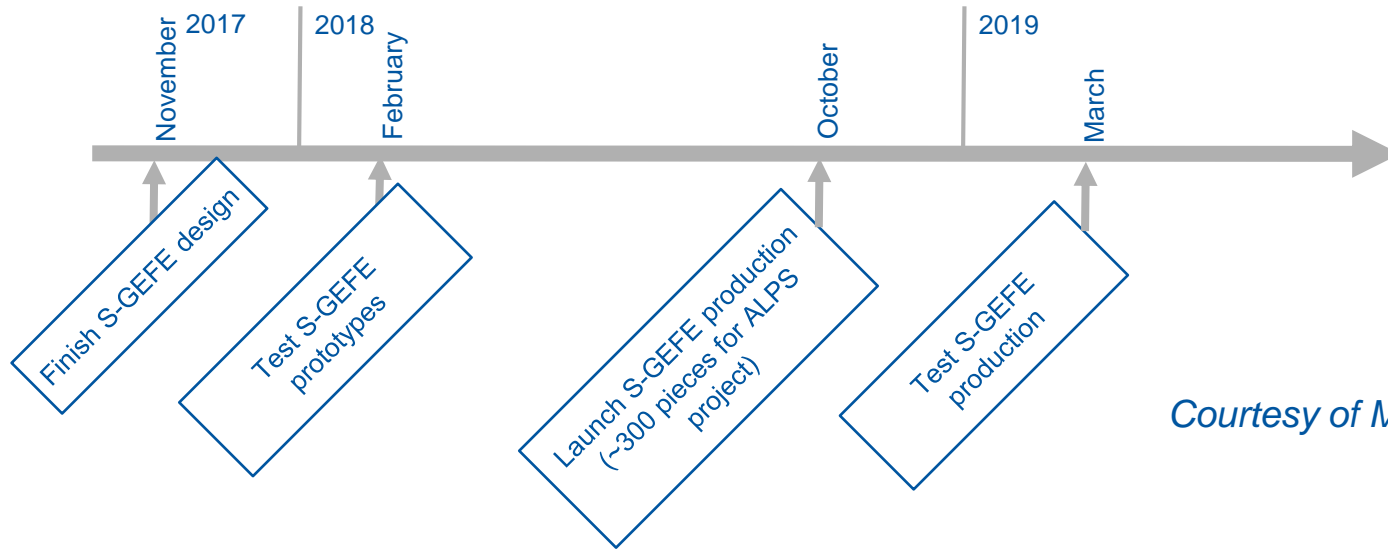


Courtesy of M. Barros Marin

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

Common solution for accelerator instrumentation optical links

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)



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

Courtesy of C. Scarcella

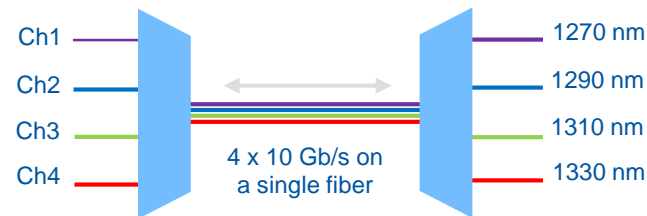
Next steps

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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See talk on Wednesday afternoon at 17h35 on
'Radiation hardness in single-mode optical links for Accelerator Instrumentation' by Carmelo Scarcella

moderate displacement damage of CWDM Lasers

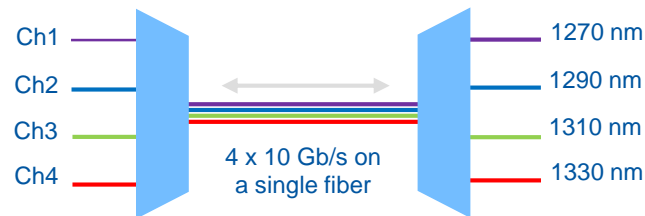
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Developments between BI-EP supported by R2E

ASICs development for Beam loss monitoring



Developments between BI-EP supported by R2E

ASICs development for Beam loss monitoring

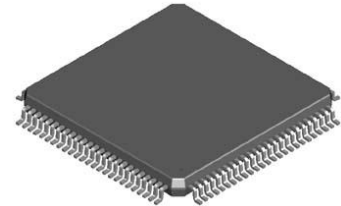
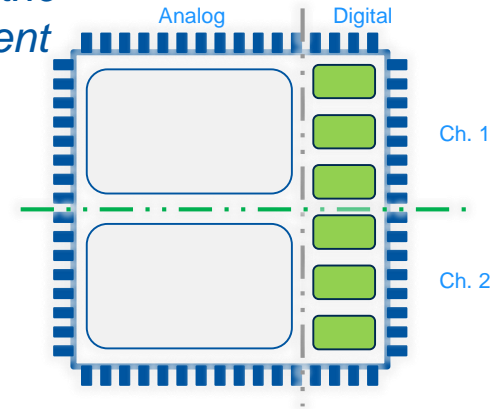
Developing two fully functional custom ASICs to evaluate the performance of two different architectures within a realistic environment

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

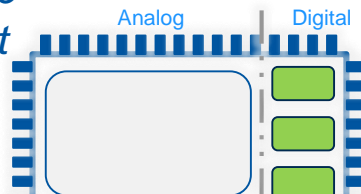
Developments between BI-EP supported by R2E

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)

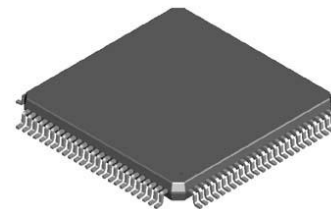


See talk on Wednesday afternoon at 17h20 on
‘ASIC design for the Beam Loss Monitor upgrade’
by **Luca Giangrande**

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

Project schedule:

- 2018 : Design and simulation
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Courtesy of L. Giangrande

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

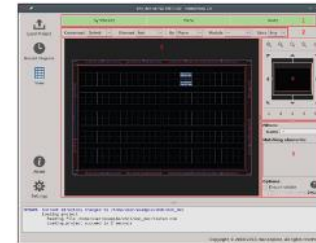


- SRAM FPGA
- RadHardened by design (no need for TMR)
- TID up to 300krad (tested also at CERN)
- ConfigRAM integrity check
- BRAM EDAC
- Packaging: plastic FG625 available
- 35k LUT4/DFF, 112 DSP, 54BRAM, 24 Clocks
- Requires a non-volatile memory for configuration

- 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 (784mm²) → *FG625 mm²*
 - *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

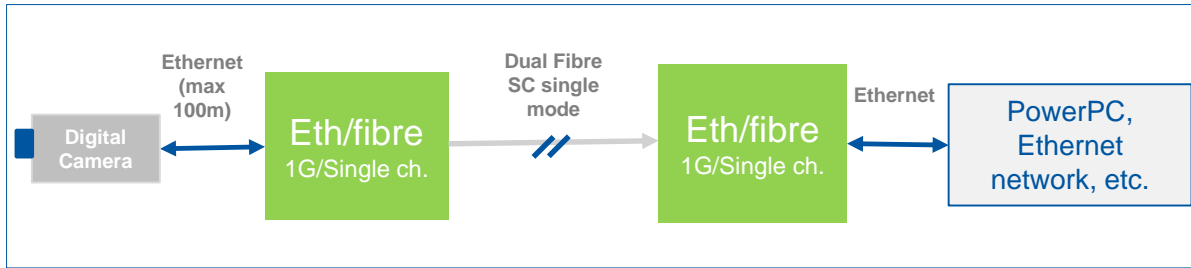
Irradiation test of Ethernet to Fibre Optics converter (ADVANTEC EKI-2741LX)



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

EKI-2741 Series

10/100/1000TX to Fiber Optic Gigabit Industrial Media Converters

NEW

Features

- Provides 1 x 1000 Mbps fiber port with SFP or SFP plus (SFP+)
- Provides 1 x 1000 Mbps fiber port with SFP or SFP plus (SFP+)
- Supports MDIX for auto-crossover
- Supports auto-negotiation
- Supports 3.00V Vcc, surge EFT protection
- Supports 4.00V Vcc, Ethernet ESD protection
- Supports industrial 42.00V Vcc, power input
- Provides flexible mounting: DIN rail & Mounting
- Provides Link Fault Pass-through (LFP)
- Supports wide operating temperature: -40~70°C (EKI-2741LX)

CE FCC

SETUP A

Introduction

EKI-2741 is an advanced industrial Gigabit Ethernet network to Digital Fiber network by transparent converting Ethernet to optic signals. Therefore EKI-2741 can be selected for "fiber-to-building" applications at central offices or local sites. EKI-2741 supports MDIX/MUX auto selection, so you don't need to use crossover wires. Furthermore, the EKI-2741 series's wide-voltage range (42V~48V Vcc). Besides, it also provides 3.00V Vcc, surge EFT protection against surge voltage. So it is suitable for harsh operating environments. EKI-2741 is an enhanced gigabit Ethernet to fiber optic converter. Aside from its standard features, the versatile EKI-2741 also has the LFP (Link Fault Pass-through) feature. When one side of the link fails, the other side continues transmitting packets, and waiting for a response that never arrives from the disconnected side. EKI-2741 will force the link to shut down as soon as required for the other side to be tested, giving the application engineer complete access to the situation.

Specifications

Communications

- Standard**: IEEE802.3, IEEE 802.3u, IEEE 802.3ab, IEEE 802.3z, IEEE 802.3x, 10/100/1000Base-TX, 1000Base-SX or 1000Base-LX
- LAN**: Ethernet 10/100
- Transmission Distance**: Fiber: Multi-mode (Up to 550m) Single-mode (Up to 10km (2741LX) or 110km (2741R)) SFP: Up to 10km (2741L) Up to 10000m (2741R)
- Transmission Speed**: Up to 1000 Mbps

Interface

- Connectors**: 1 x RJ-45 1 x SC (for fiber connectors (EKI-2741LX) or 1 x SFP-type fiber connectors (EKI-2741R)) 8-pin RJ45 shielded (one terminal green (see manual))
- LED Indicators**: Fiber: LINK/ACT Ethernet: 1000M, LINK/ACT Port Status: LFP
- Power Consumption**: 5.20W (EKI-2741R) 1.50W (EKI-2741LX) 5.30W (EKI-2741L) 2 x temperature: 1~40°C

Mechanics

- Dimensions (W x H x D)**: 37 x 140 x 95 mm
- Backplane**: IP20 (Mount panel with solid mounting kits)
- Mounting**: DIN-rail, Wall

Protection

- ESD (Human)**: 4.00V Vcc
- Surge EFT (per part)**: 1.000V Vcc
- Power Reverse**: Protect
- Overload**: 0.5A/1V (Reversible Fault)

Environment

- Operating Temperature**: -40~70°C (-40~167°F) 0~70°C (32~158°F)
- Storage Temperature**: -40~70°C (-40~167°F)
- Operating Humidity**: 5~95% (non-condensing)
- Storage Humidity**: 5~95% (non-condensing)

Substrate: PCB: 125,500 (for EKI-2741LX/LR)

Certifications

- Safety**: UL 60950-1, CAN/CSA C22.2 No.60950
- EMC**: IEC 61000-4, EN 61000-4, EN 61000-3-2, EN 61000-3-3, EN 61000-3-4, EN 61000-3-5, EN 61000-3-6, EN 61000-3-7, EN 61000-3-8, EN 61000-3-9

Ordering Information

- EKI-2741R**: Industrial Gigabit Ethernet to SFP Type Fiber Optic Converter
- EKI-2741LX**: Industrial Gigabit Ethernet to 1000Base-SX SC Type Fiber Optic Converter
- EKI-2741L**: Industrial Gigabit Ethernet to 1000Base-LX SC Type Fiber Optic Converter
- EKI-2741LX**: Industrial Gigabit Ethernet to 1000Base-LX SC Type Fiber Optic Converter (Wide Temp)

ADVANTECH Industrial Ethernet Solutions

For product specifications, see subject to change without notice. Last updated: 27 May 2016

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

Courtesy of S. Burger



Testing COTS to radiation

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

EKI-2741 Series 10/100/1000TX to Fiber Optic Gigabit Industrial Media Converters

NEW

Features

- Provides 1 x 1000 Mbps fiber port with SFP or SFP plus (SFP) connector for 1000Base-SX/LX device
- Provides PoE support for PoE/PoE+ device
- Supports MDI/MDI-X auto crossover
- Supports auto negotiation
- Supports 3.000 Vdc surge EFT protection
- Supports 4.000 Vdc Ethernet ESD protection
- Supports industrial 4-20 mA power input
- Provides flexible mounting: DIN-rail & Wallmounting
- Provides Link Fault Pass-through (LFP)
- Supports wide operating temperature: -40~70°C (EKI-2741LX)

Introduction

EKI-2741 is an enhanced Gigabit Ethernet network to fiber optic converter by transparent converting Ethernet signals to optical signals. Therefore, EKI-2741 can be used for "fiber-to-building" applications at central offices or local sites. EKI-2741 supports MDI/MDI-X auto selection, so you don't need to use crossover wires. Furthermore, the EKI-2741 supports a wide voltage surge input $\pm 3.000 Vdc$. Besides, it also provides 3.000 Vdc surge EFT protection against static voltage, so it is suitable for harsh operating environments. EKI-2741 is an enhanced gigabit Ethernet to fiber optic converter. Aside from its standard features, the versatile EKI-2741 also has the LFP (Link Fault Pass-through) feature. When one side of the link fails, the other side continues transmitting packets, and waiting for a response that never arrives from the disconnected side. EKI-2741 will force the link to shut down as soon as required for the other side link being, giving the application software a chance to repair the situation.

Specifications

Protection

- ESD (Human): 4.000 Vdc
- Surge (EFT for power): 3.000 Vdc

Setup A

Mechanism

- Dimensions (W x H x D): 37 x 140 x 95 mm
- Backplane: 175°C. Metal coat with solid mounting hole
- Mounting: DIN-rail, Wall

• EKI-2741E Industrial Gigabit Ethernet to 1000Base-SX/SC Type Fiber Optic Converter

• EKI-2741L Industrial Gigabit Ethernet to 1000Base-LX/SC Type Fiber Optic Converter

• EKI-2741LX Industrial Gigabit Ethernet to 1000Base-LX/SC Type Fiber Optic Converter. Wide Temp.

ADVANTECH Industrial Ethernet Solutions

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Courtesy of S. Burger

Developing rad-tolerant solutions

Beam imaging using Optical fibre bundles

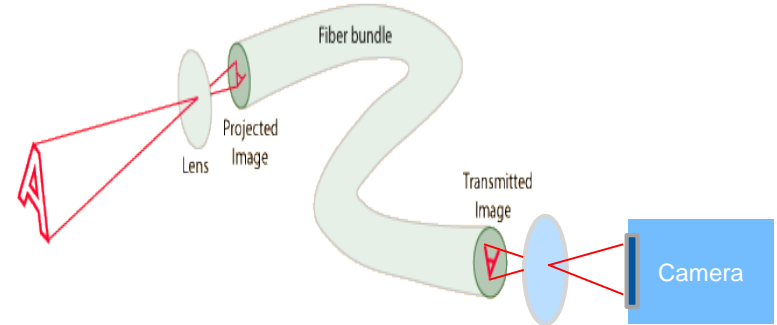
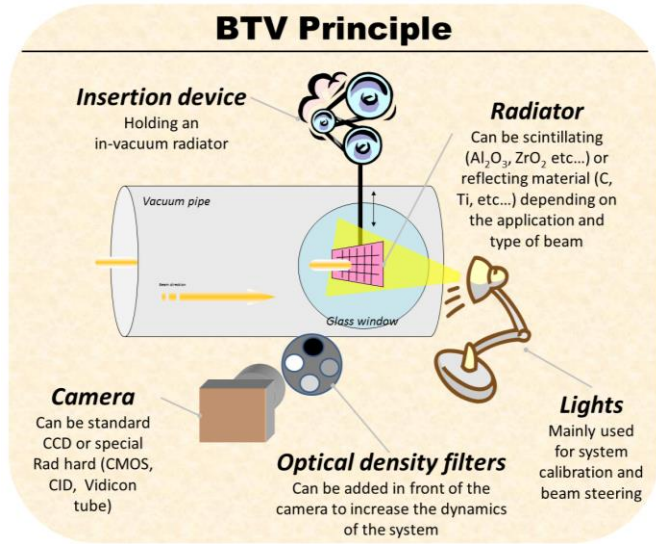


Developing rad-tolerant solutions

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



Developing rad-tolerant components

Beam imaging using Optical fibre bundles

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‘Radiation hardness tests of Optical fibre components’
by **Damiano Celeste**

Courtesy of D. Celeste



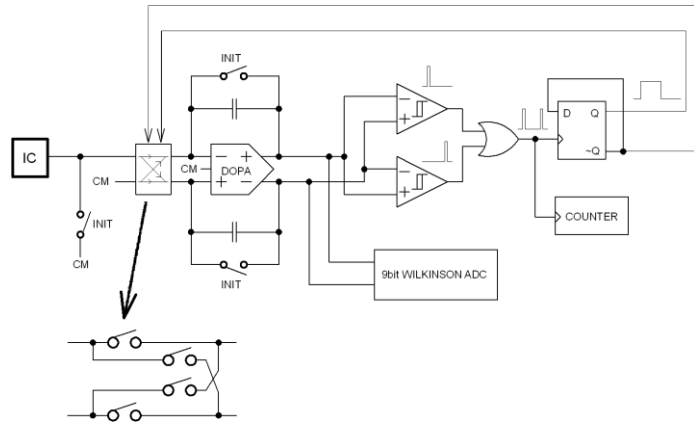
Conclusions

- **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**

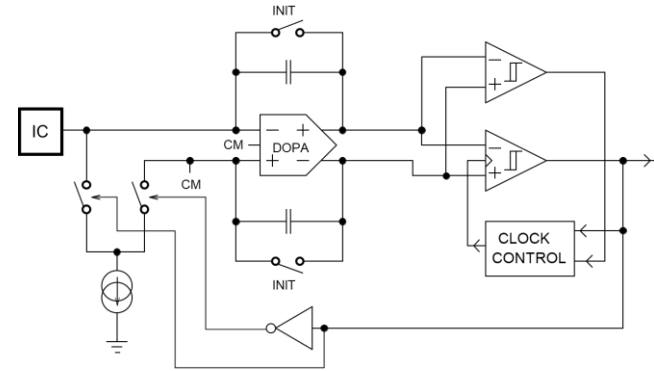
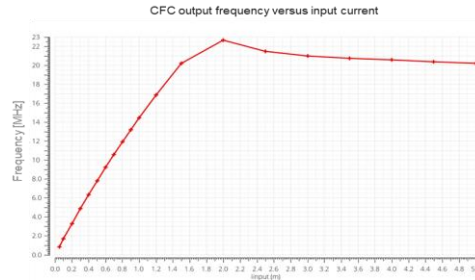
Thanks for your attention



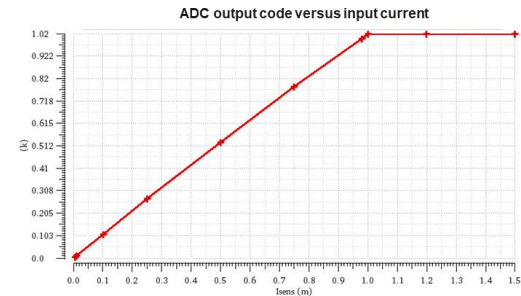
Architectures comparison



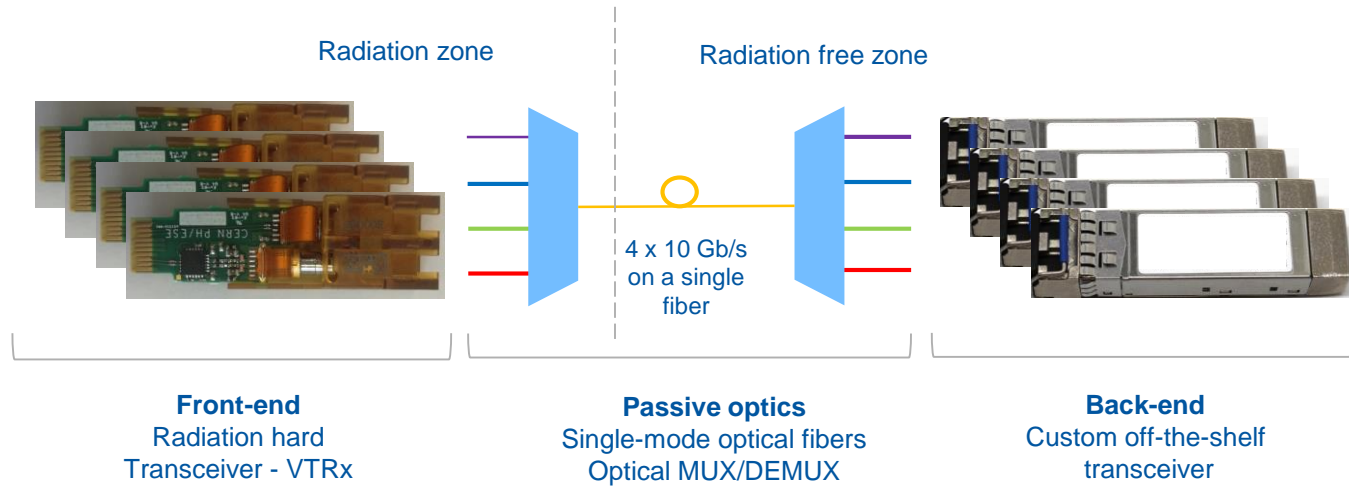
Fast response to large current steps.
 INL (before calibration) in the higher range (1pA~1mA): 15 %
 INL (before calibration) in the lower range (1pA~10µA): 0.5 %
 RMS noise in the 10µs integration window (Wilkinson ADC): < 2 nA
 Current consumption: 15 mA



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



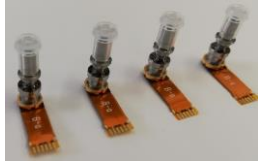
CDWM Single-Mode Versatile link



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

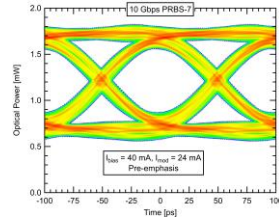
Project Milestones

CWDM COTS EEL procurement

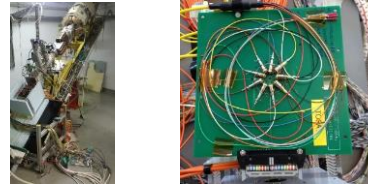


Progress to date

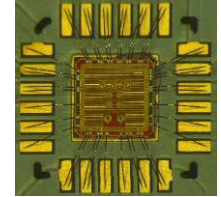
10.24 Gb/s uplink operation



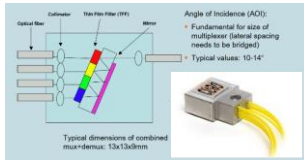
Displacement damage EEL
 $5 \cdot 10^{14}$ n/cm² MeV neutrons fluence



GBLD Laser driver
 TID test

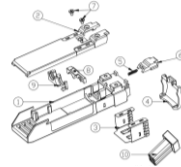


CWDM MUX radiation tolerance



Next steps

Standard SFP cage compatibility



Link specs definition and production

