Progress on next generation rad-hard optical links for Beam Instrumentation (BE-BI) applications

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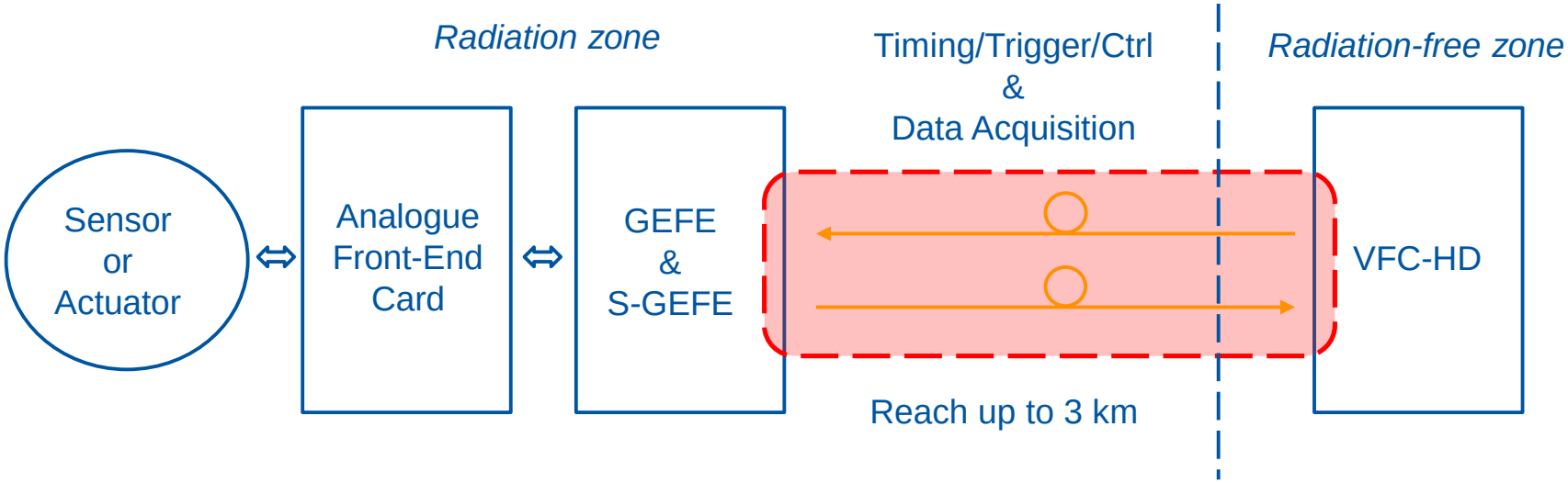
Outline

- Optical Links for Accelerator Instrumentation
  - project timeline
  - versatile link and Single-mode VTRx
- Single-mode Edge-Emitting Laser selection
  - radiation tolerance and system performance
- High capacity data link
  - 10 Gb/s transmitter
  - wavelength division multiplexing CWDM
- Future steps
- Summary

Optical Links for Accelerator Instrumentation

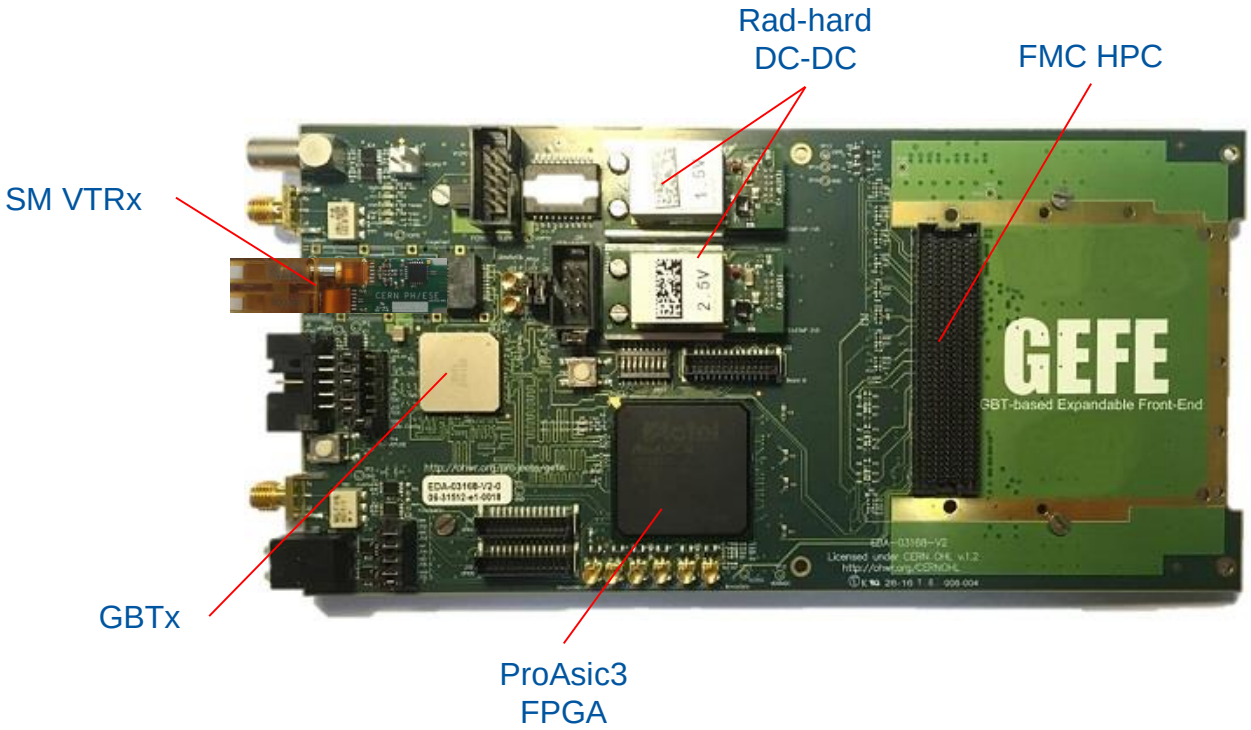
The Accelerator Instrumentation Group (BE/BI) is moving towards common readout solutions

- Back-End readout based on VFC-HD
- Front-End readout based on GEFE/S-GEFE

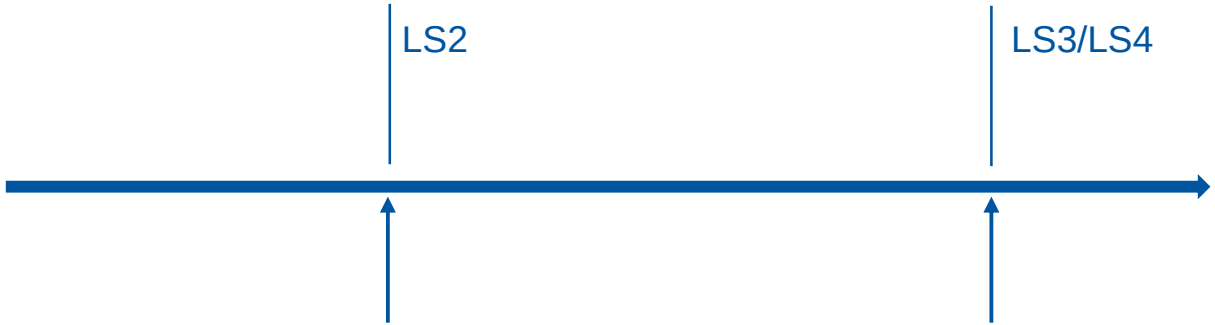


The GBT-based Expandable Front-End (GEFE)

Common hardware development ongoing for LS2 upgrades

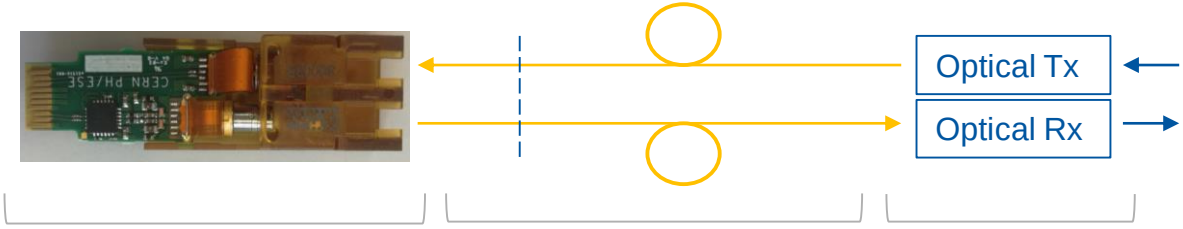


Project timeline



	LS2	LS3/LS4
Rad-Hard Link	GBTx + SM VTRx	LpGBT + New SM VTRx
Rad-Hard DFE	GEFE & S-GEFE	Distributed IO Tier (BE-CO) or S-GEFE 2
Users	New SPS BPM system (“ALPS”) Motor control optical interface (“MCOI”) …	LHC BPMs (LS3) SPS BLMs (LS3) / LHC BLMs (LS4) …
Total links	~ 300	~ 5000 - 10000
Data-rates	GBTx Tx 4.8 Gbps Rx 4.8 Gbps	LpGBT Tx up to 10 Gbps Rx 2.5 Gbps

Versatile link in Accelerator instrumentation



Front-end
Radiation hard
Transceiver - VTRx

Passive optics
Optical fibers
And connectors

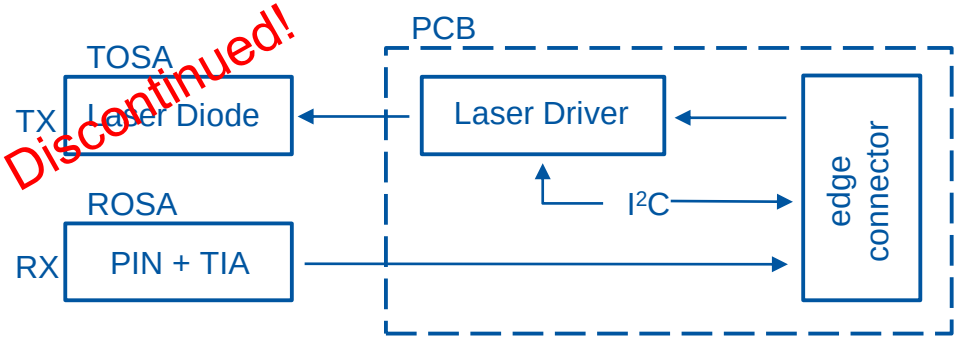
Back-end
Custom off-the-shelf
transceiver

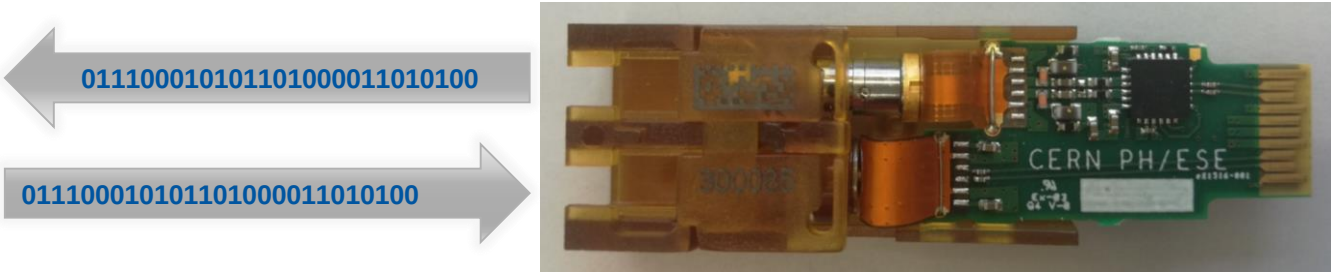
Parameter	Value	Units
Max Bit Rate	4.8	Gbps
Wavelength	1310	nm
Total ionizing dose (TID)	10	kGy
Fluence	$5 \cdot 10^{14}$	n/cm^2 MeV neutrons

Compatible with fibre plant in accelerators
Production for experiments 2016 to mid-2018 for LS2 installation

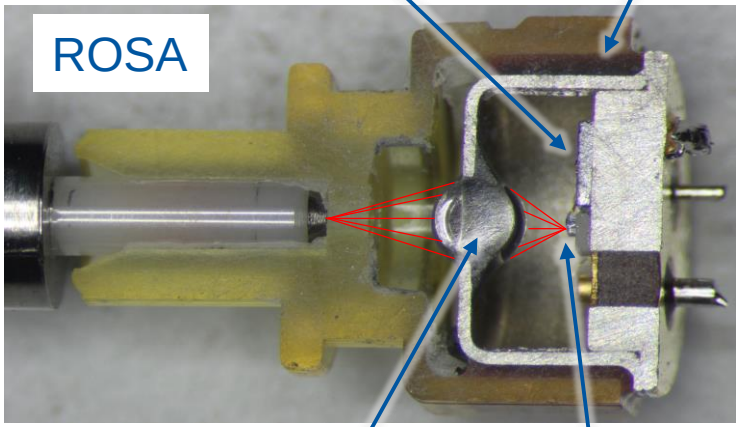
Single-mode Versatile Link Transceiver - VTRx

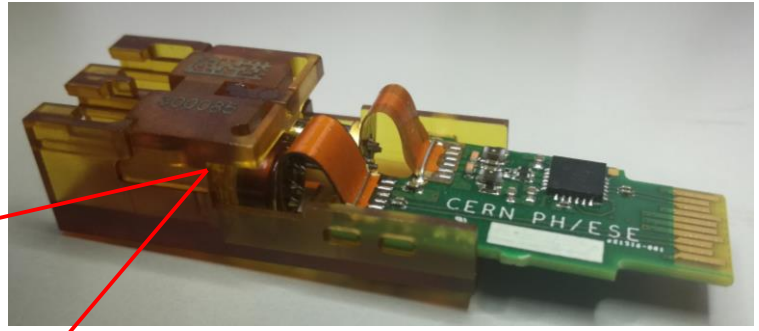
- Front-End pluggable module
- Receiver
  - COTS InGaAs Photodiode
  - Transimpedance amplifier GBTIA v3
- Transmitter
  - COTS Edge emitter DFB laser
  - Laser driver GBLD v4.2

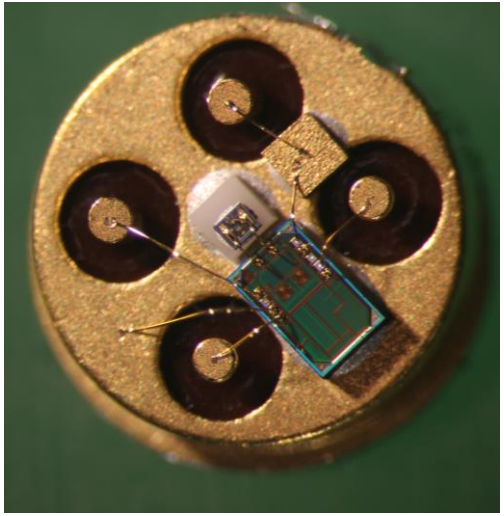




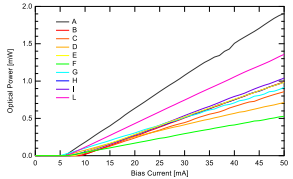
Receiver - VRx

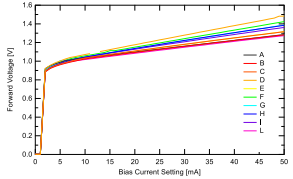


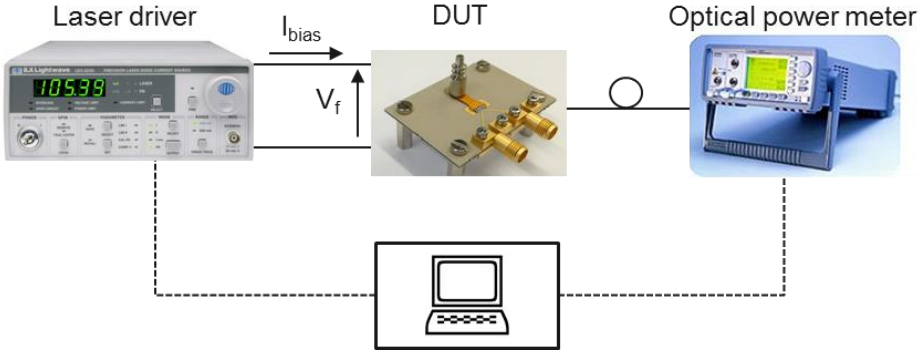




Single-mode TOSA selection

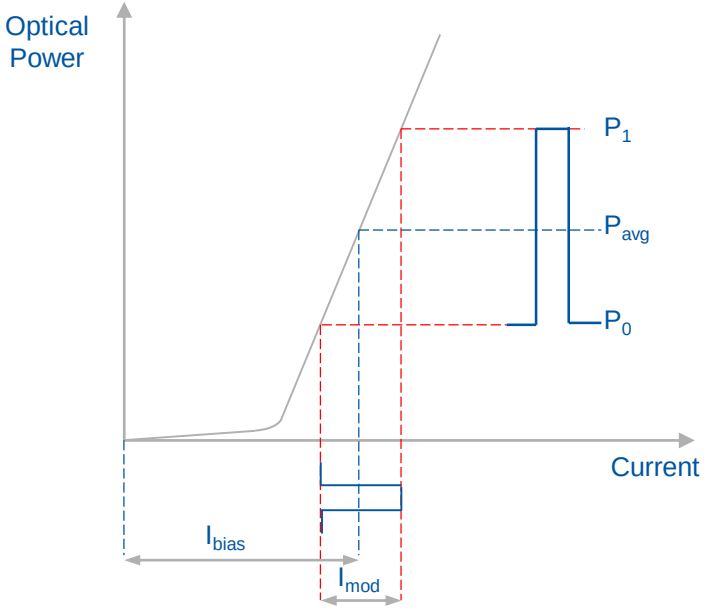


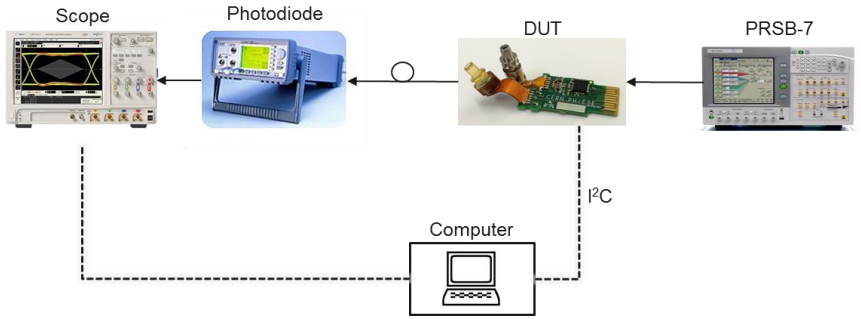


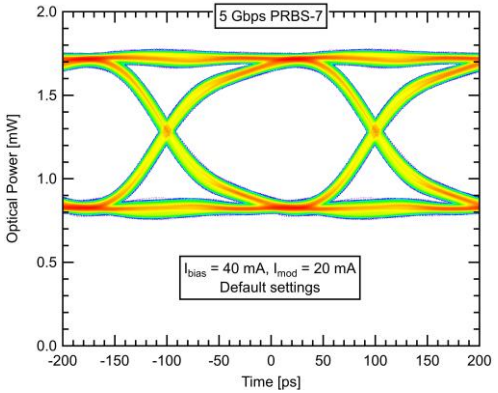


TOSA ID	Laser type	Note
A	FP	VTRx 1st generation
B	FP	
C	FP	
D	FP	
E	FP	
F	FP	
G	DFB	Optical isolator
H	DFB	
I	DFB	Optical isolator
L	DFB	Optical isolator

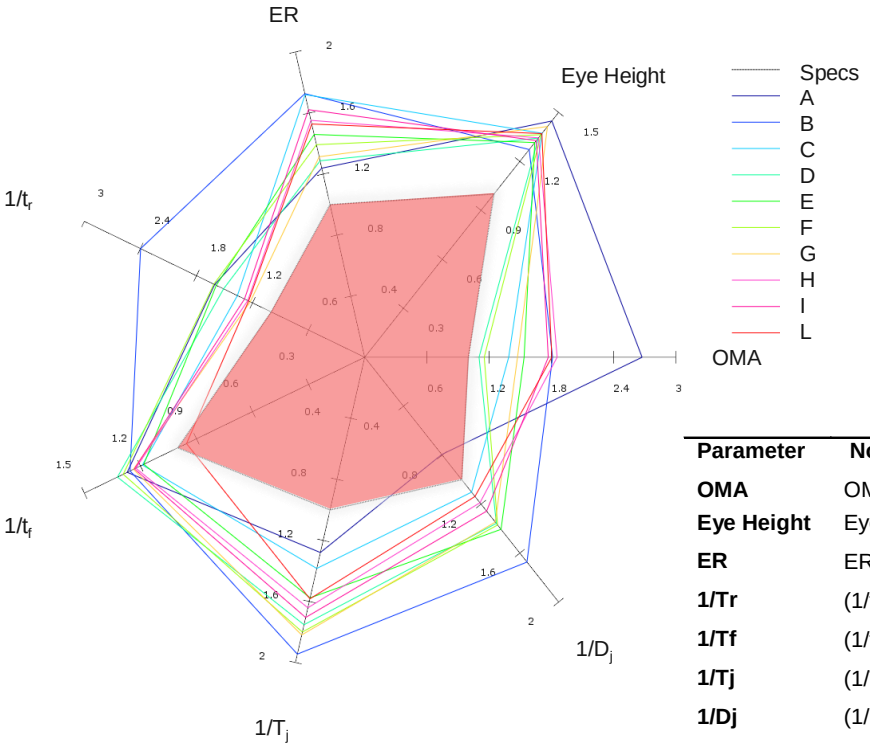
Single-mode TOSA selection







Dynamic performance at 5 Gbps



Most of the tested devices meet the Versatile Link specifications

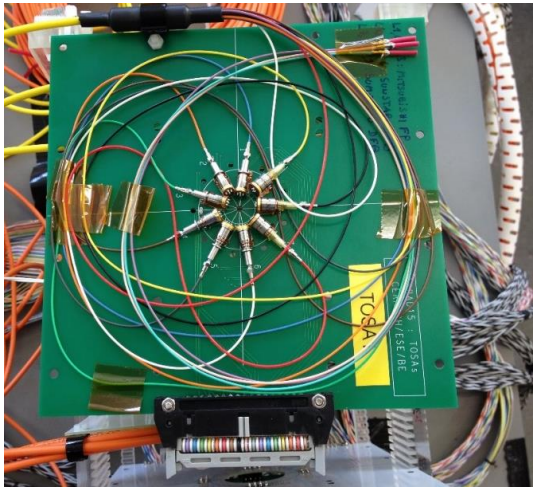
Parameter	Normalization	A	B	C	D	E	F	G	H	I	L
OMA	OMA/300µW	2.68	1.81	1.39	1.10	1.54	1.15	1.47	1.86	1.77	1.80
Eye Height	Eye Height/(0.6*OMA)	1.45	1.27	1.37	1.34	1.32	1.36	1.41	1.34	1.33	1.37
ER	ER/3	1.24	1.73	1.72	1.29	1.46	1.39	1.31	1.55	1.62	1.53
1/Tr	(1/tr)/(1/70ps)	1.61	2.40	1.36	1.51	1.59	1.61	1.22	1.25	1.29	1.24
1/Tf	(1/tf)/(1/70ps)	1.27	1.26	1.19	1.32	1.18	1.29	1.24	1.22	1.23	0.95
1/Tj	(1/Tj)/(1/0.25UI)	1.28	1.94	1.38	1.75	1.58	1.80	1.82	1.64	1.70	1.58
1/Dj	(1/Dj)/(1/0.12UI)	0.79	1.67	1.10	1.36	1.41	1.37	1.35	1.19	1.26	1.14
				FP				DFB			

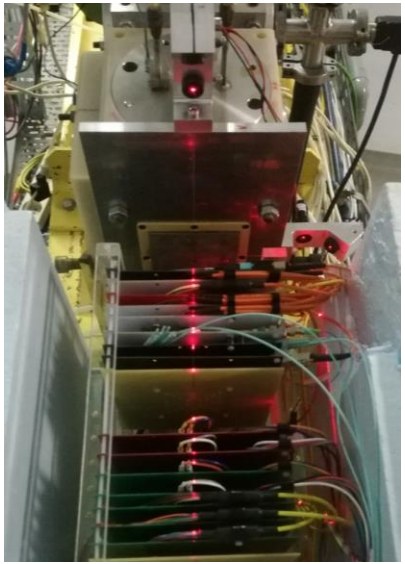
Note: Bit rate = 5 Gbps, UI = 200 ps, I_{bias} = $I_{bias\ max}$ =40 mA, I_{mod} = $I_{mod\ max}$ =24 mA

Displacement damage – TOSA in n-beam

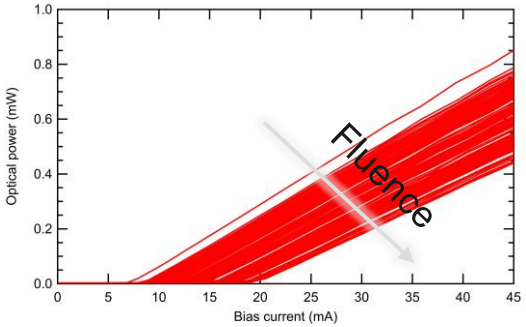
Single-mode TOSAs exposed to neutron beam at UC Louvain cyclotron facility

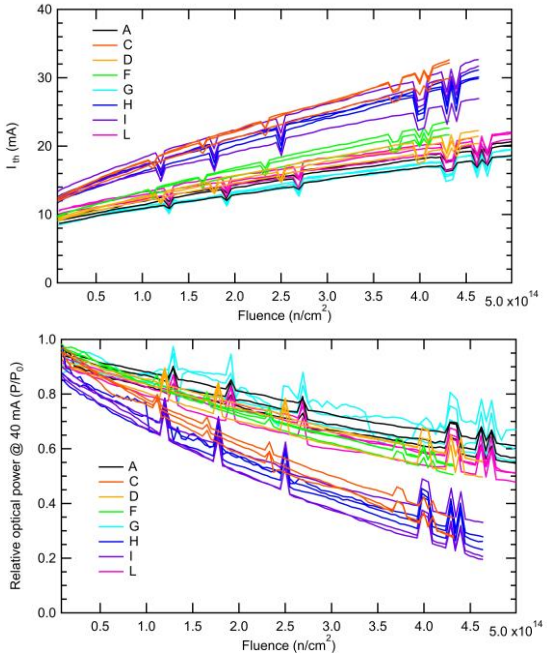
Irradiation with fluence up to 5 x 10^{14} n/cm^2 20 MeV neutrons

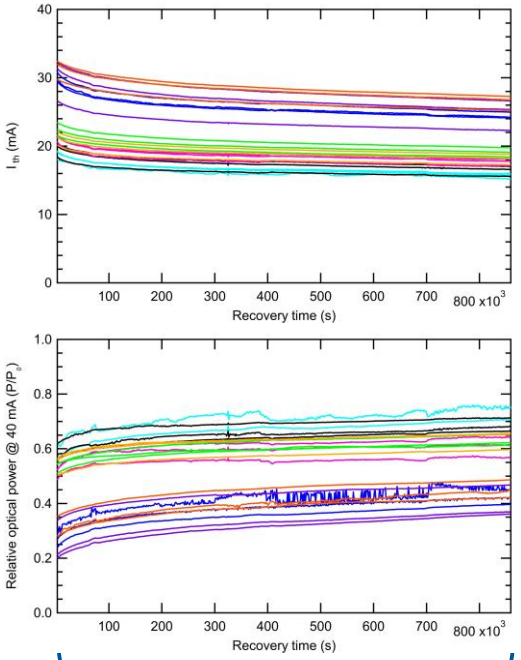




Displacement damage





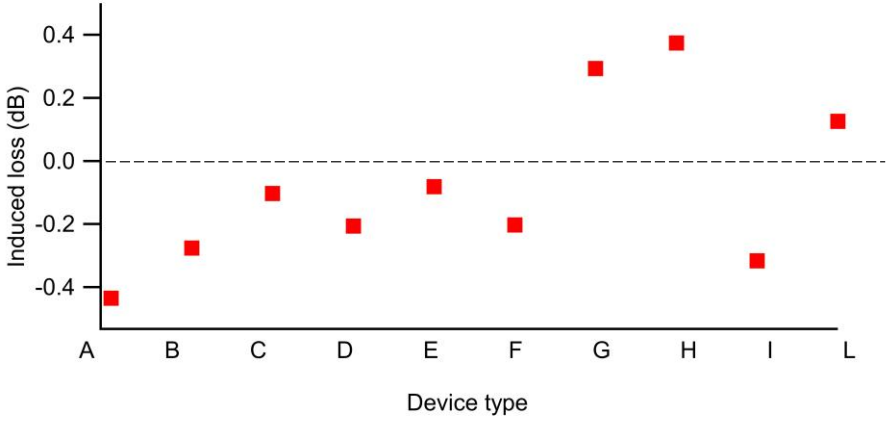


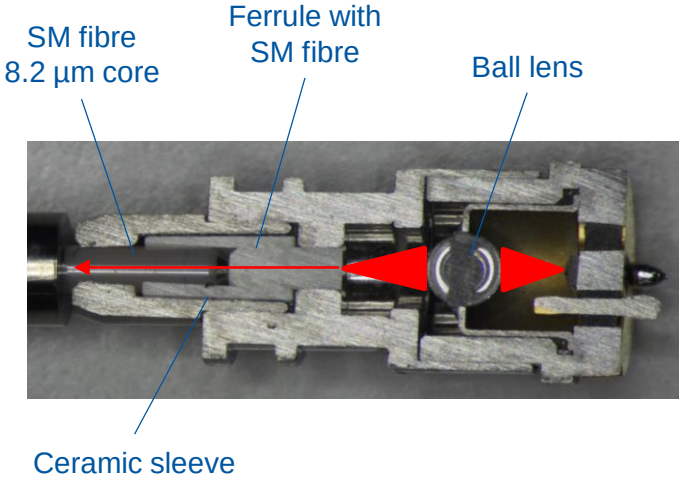
10 days annealing

Output optical power decreases due to threshold current rising

Best in class with optical power drop of 40 % at 40 mA bias current

TOSA TID test





Irradiated with Gamma rays (Cobalt-60) to 10 kGy

@ SYNERGY HEALTH DANIKEN AG

No induced loss due to darkening of passive optical components

High data-rate demand

Increasing the lane rate from 4.8 Gbps to 10.24 Gbps

compatible with CERN rad-hard serialiser/deserialiser upgrade from GBTx to LpGBT

Wavelength division multiplexing

multiple lanes at different wavelengths are multiplexed into and out of a single fiber

You can find the last update on LpGBT at:
https://espace.cern.ch/GBT-Project/LpGBT/Specifications/LpGbtxSpecifications.pdf

10 Gbps VTx operation

All evaluated TOSAs rated for 10 Gbps operation

Custom rad-hard ASIC – GBLD V4.2

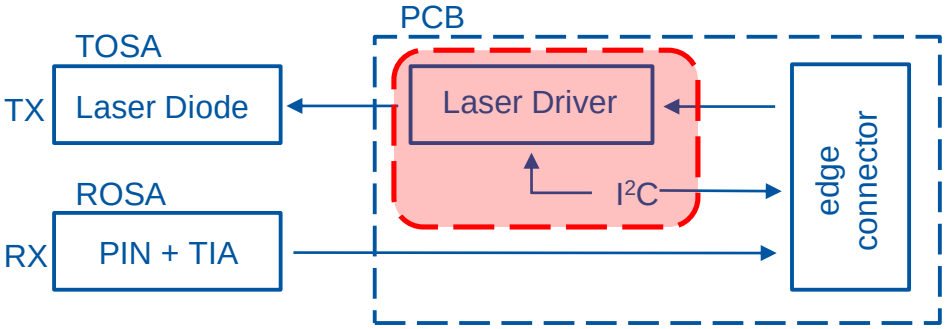
I_{bias} = 2 ÷ 43 mA

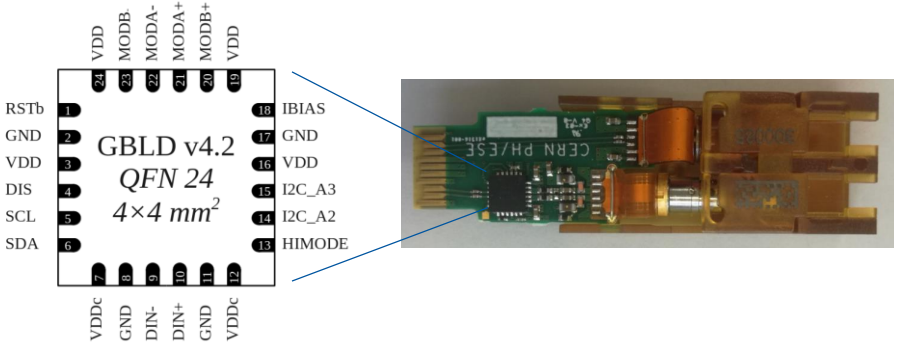
$I_{modulation}$ = 4 ÷ 24 mA

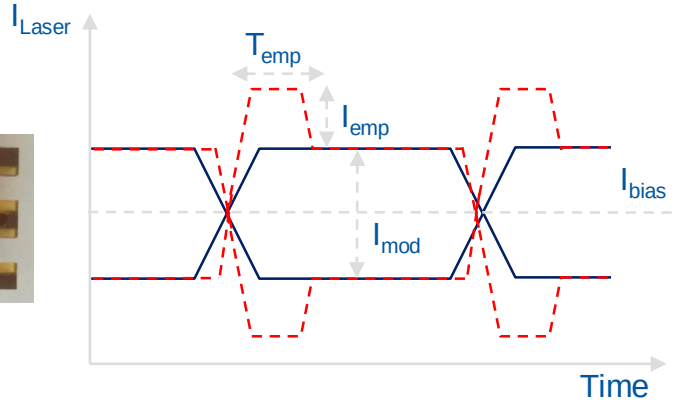
$I_{emphasis}$ = 0 ÷ 24 mA

$T_{emphasis}$ = 60 ÷ 90 ps

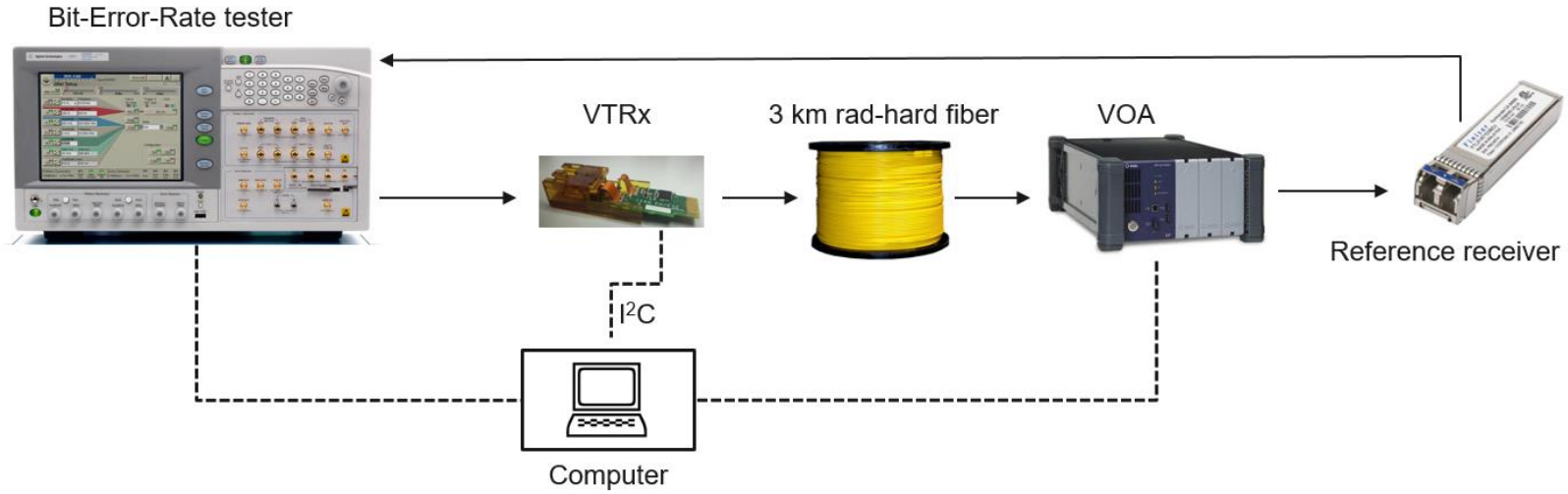
} Enhancing the frequency response







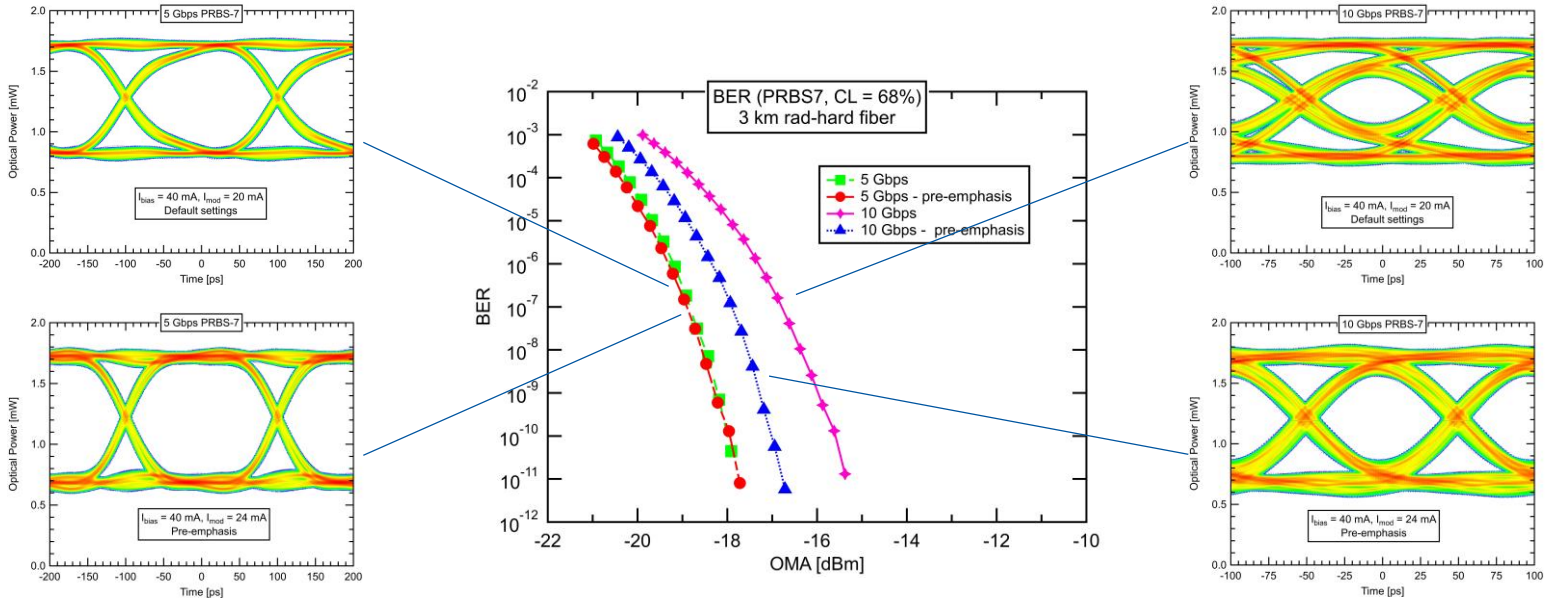
Receiver sensitivity test



VTRx testing conditions

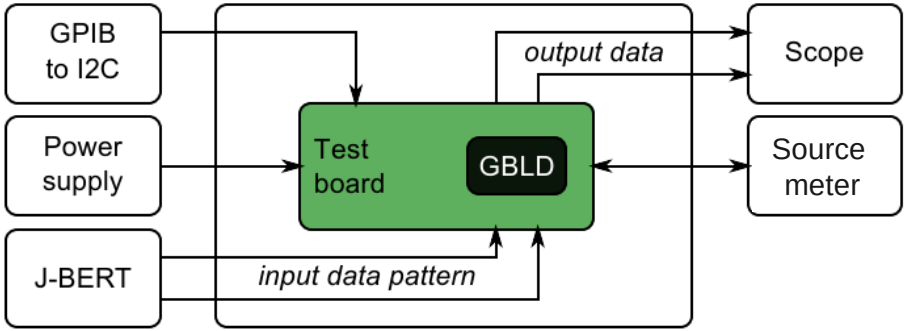
	I_{bias} = 40 mA, I_{mod} = 20 mA (default settings)	I_{bias} = 40, I_{mod} = 24 mA I_{emp} = 24 mA, T_{emp} = 90 ps
5 Gbps	●	●
10 Gbps	●	●

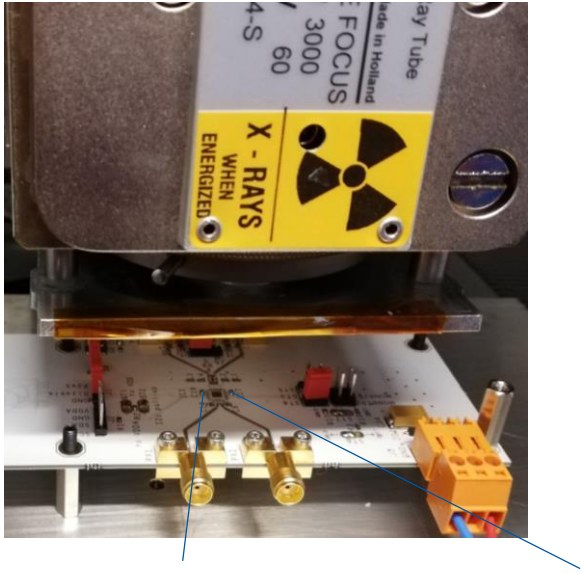
BER Test

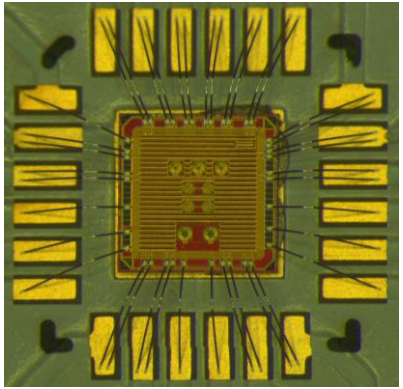


Wide 10 Gbps open eye diagram and negligible receiver sensitivity penalty compared to 5Gbps operation

X-ray test GBLD







Dose steps: 2, 4, 6, 8, 10, 15, 20, 30, 40 and 50 kGy

Bias current and eye diagram measurement

I_{mod} sweep from 4 mA to 24 mA with 4 mA step size

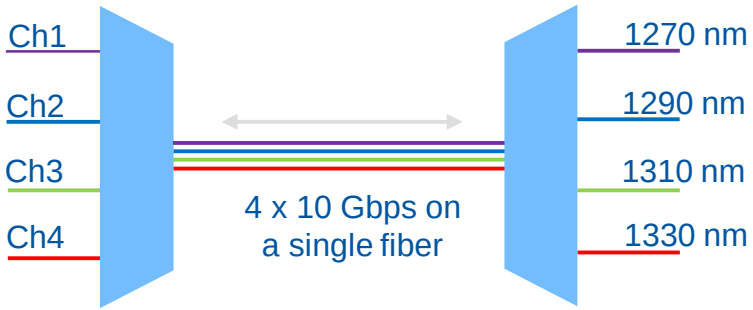
I_{emp}: 6 mA and 12 mA

Test result analysis in progress

Coarse wavelength division multiplexing CWDM

Wavelength division multiplexing

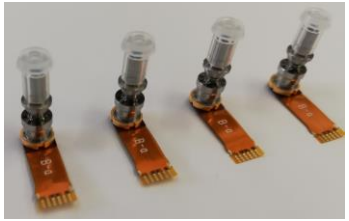
multiple lanes at different wavelengths are multiplexed into and out of a single fiber



CWDM TOSAs

Supplier A

Parameter	Symbol	Condition		Min.	Typ.	Max.	Unit
Threshold current	Ith	CW		—	5	15	mA
		CW, Tc=-5 to +80°C		—	—	40	
Optical output power	Pf	CW, If=Ith+25mA		-1	2	—	dBm
		CW, If=Ith+25mA, Tc=-5 to+80°C		-4	—	—	
Operating voltage	Vf	CW, If=80mA, Tc=+80°C		—	—	2	V
Slope efficiency	Se	CW, Average(Ith to Ith+25mA)		0.032	0.063	—	mW/mA
Peak wavelength	λp	CW, Pf=+2dBm	K60S	—	1271	—	nm
			K24S	—	1291	—	
			J88S	—	1311	—	
			J54S	—	1331	—	



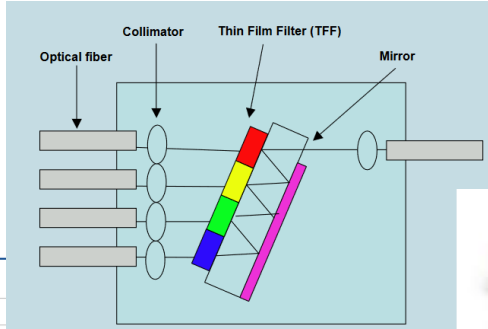
Supplier B

Parameters	Symbol	Min.	Typ.	Max.	Unit	Condition	Inspection
Output Optical Power	Pf	0.65	---	---	mW	CW, Iop=Ith+20mA,	100%
Threshold Current	Ith	---	7	---	mA	---	100%
Peak Wavelength	λp	1264.5	1271	1277.5	nm	---	---
		1284.5	1291	1297.5		---	---
		1304.5	1311	1317.5		---	---
		1324.5	1331	1337.5		---	---
Side mode suppression ratio	SMSR	35	40	---	dB	CW	---

Neutron irradiation test in November 2018 at UCL Louvain-la-Neuve

LIV and optical spectrum measurement during the test

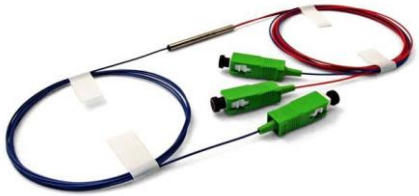
Optical MUX/DEMUX



Specifications

Parameters	Coarse Wavelength Division Multiplexer – mux/demux (all values refer to multimode)		
Channels	4, 4+ upgrade		
Center Wavelength [nm]	choice of 4 wavelengths within one band		
Band 1 (red band)	1471 / 1491 / 1511 / 1531 / 1551 / 1571 / 1591 / 1611		
Band 2 (blue band)	1271 / 1291 / 1311 / 1331 / 1351 / 1371 / 1391 / 1411 / 1431 / 1451		
	Upgrade: remaining wavelengths of band		
	other wavelength upon request; please contact CUBO		
Optical Bandwidth	> 13 nm (higher bandwidth on request)		
Insertion Loss *	4 channel CWDM	Standard < 1.9 dB	Premium < 1.7 dB
	4+ upgrade channel CWDM	Standard < 2.0 dB	Premium < 1.8 dB
Isolation **	adjacent channel	> 30 dB	
	non-adjacent channel	> 40 dB	
	Isolation Spectral Range Band 1 (red)	1460-1620 nm	
	Isolation Spectral Range Band 2 (blue)	1260-1460 nm	
Return Loss *	> 10 dB		
Directivity (for mux)	> 40 dB		
Max. optical power	250 mW		
Operating Temperature	0°C to 70°C (-40°C to 85°C on request)		
Storage Temperature	-40°C to 85°C (when removed from plastic package)		
Package Dimensions	19 x 15.5 x 9 mm^3		

2 channel version



Wavelength range	Pass Band Reflect Band
Insertion Loss *	< 1.0 dB

Optical MUX/DEMUX

Ordered 4 channel modules (10 parts) at CERN by the end of Oct. 2018

Gamma test to validate insertion loss and wavelength shift

Will be used to build the neutron irradiation test setup

4 channel Mux or Demux; Wavelength: 1271-1331nm

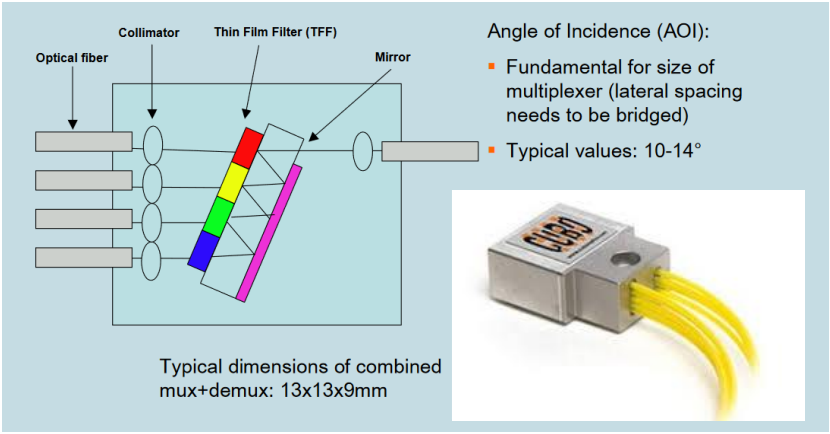
Grade: Standard

Insertion Loss w/o connectors: 1.9dB

Fiber Type: SMF-28 + loose tube (900µm)

Fiber Length: 1m

Connectors: LC/PC



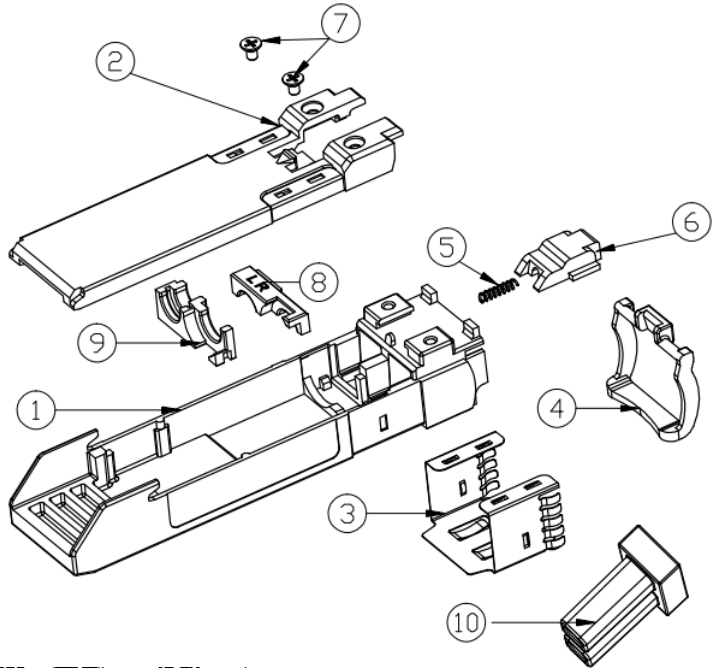
Back-end solutions

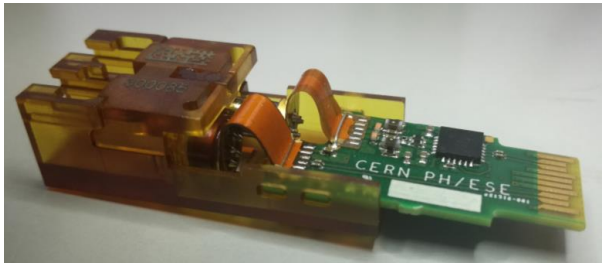
SFP+ 10G
Douplex LC connector

SFP+ 10G
Single LC connector

QSFP internal MUX and DEMUX
4 Rx channels (10G)
4 Tx channels (10G)
Douplex LC connector

SFP standard housing





First generation VTRx housed into customized plastic injection molding ‘latch’ requiring bolt fastener

Ordered 20 SFP standard off-the-shelf metal housing kits

PCB design might require changes, including data lines inversion

Summary

First phase of the project

- selection of COTS Single-Mode Laser
- functional test and radiation tolerance validation

Second phase of the project

- demonstration of 10 Gb/s VTRx (uplink)
- TID test GBLD
- functional test of CWDM Lasers
- solutions for standard SFP cage compatibility

Next steps

- neutron irradiation test on CWDM Lasers
- radiation tolerance validation of WDM MUX and DEMUX
- defining final link architecture
- moving towards parts procurement and production