The Versatile Transceiver

Development Status

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CERN PH-ESE-BE

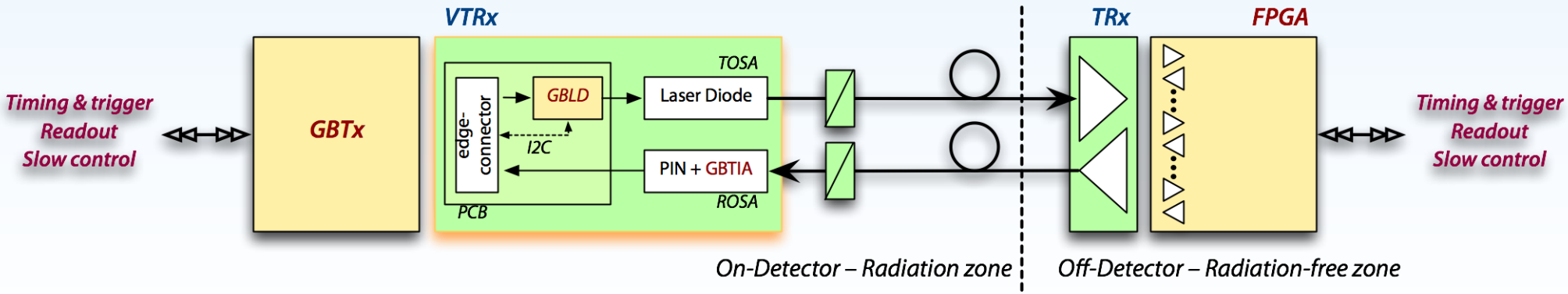
Outline

- Introduction
- Component testing
  - TOSA, ROSA
- Transceiver design
  - PCB versions, Latch
- Transceiver testing
- Future work
- Summary

Versatile Link Project

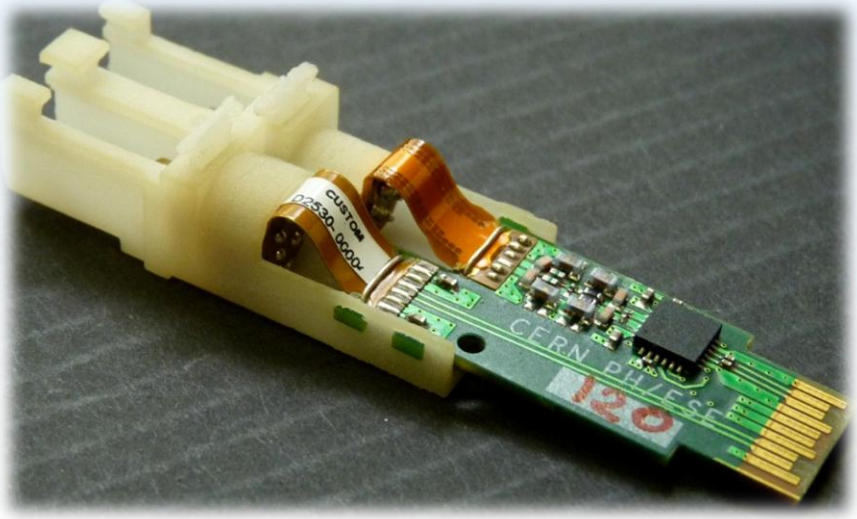
- Optical layer linking front-end to back-end up to 150 m distant.
- Bi-directional @ 5 Gbps
- Two Point-to-point solutions
  - 850 nm Multimode
  - 1310 nm Single-mode
- Front-end pluggable module
- Rad-hard front-end

- Joint Project Proposal submitted to ATLAS & CMS upgrade steering groups in 2007 and endorsed in 2008
- Project Kick-off: April 2008
  - Phase I: Proof of Concept (18mo)
  - Phase II: Feasibility Study (18mo)
  - (Consolidation)
  - Phase III: Pre-prodn. readiness (18mo)



Versatile Transceiver

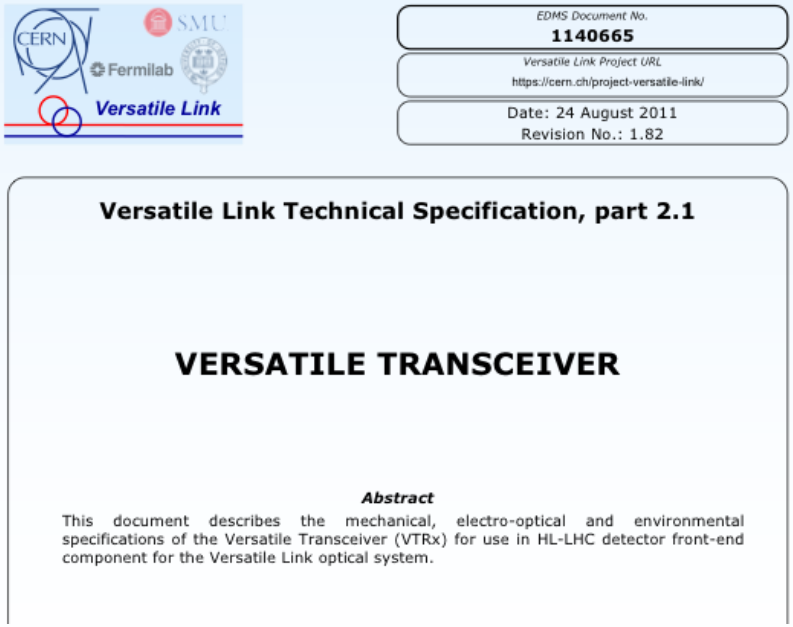
- Based on SFP+
  - Industry standard
  - Can support target speed: 5 – 10 Gb/s
- Customization
  - Radiation-qualified commercial Laser and Photodiode
  - Custom-designed radiation hard ASICs: GBLD and GBTIA
  - Non-magnetic package: plastic LC latch
  - Low mass



VTRx prototype with commercial driver and EE laser

Versatile Transceiver Specifications

- Specifications are available on EDMS
  - Sub-components
  - Entire module



EDMS Document No.
1140665

Versatile Link Project URL
https://cern.ch/project-versatile-link/

Date: 24 August 2011
Revision No.: 1.82

Versatile Link Technical Specification, part 2.1

VERSATILE TRANSCEIVER

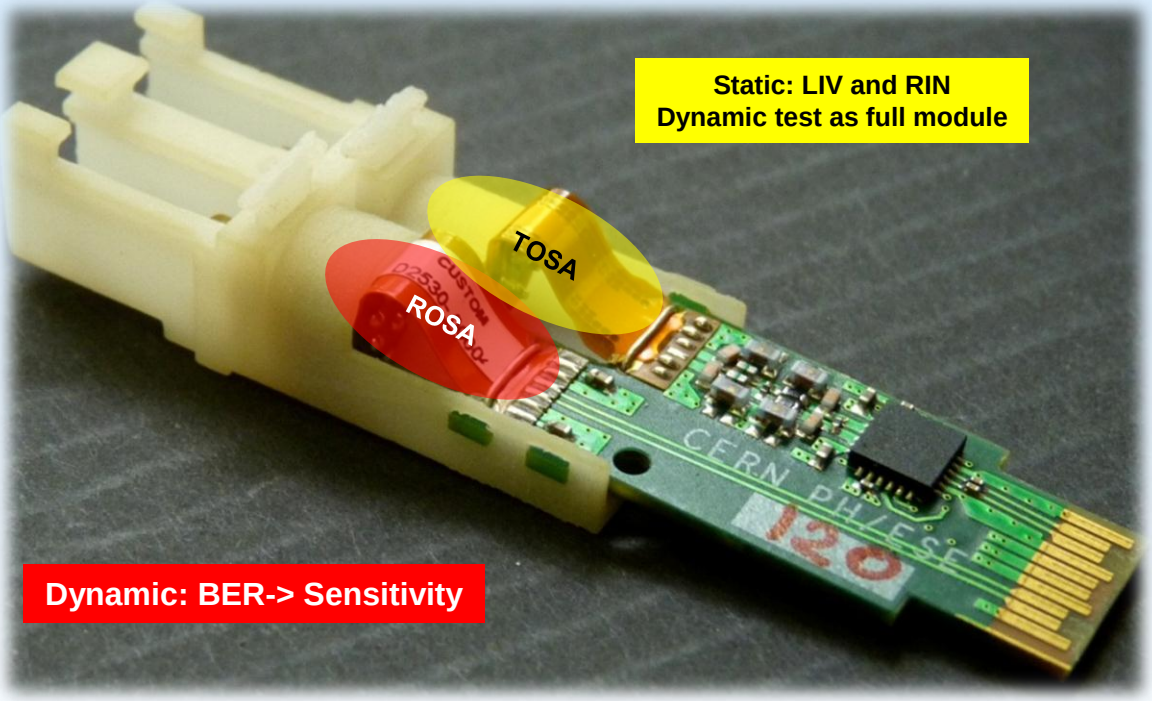
Abstract

This document describes the mechanical, electro-optical and environmental specifications of the Versatile Transceiver (VTRx) for use in HL-LHC detector front-end component for the Versatile Link optical system.

#	Specification	Min	Typ	Max	Unit	Notes
4.1.1	TX OMA	300			µW	(-5.2 dBm)
4.1.2	TX Extinction Ratio	3			dB	
4.1.3	TX Eye Opening	60			%	of OMA
4.1.4	TX rise/fall time			70	ps	20%-80%
4.1.5	TX output Total Jitter			0.44	UI	VTRx contribution is 0.25 UI, corresponding to 52 ps at 4.8 Gb/s
4.1.6	TX output Deterministic Jitter			0.26	UI	GBLD spec 0.12 UI (25 ps at 4.8 Gb/s) VTRx contribution is 0.12 UI (25 ps at 4.8 Gb/s)
4.1.7	TX Eye Mask					See Appendix
4.1.8	TX output wavelength		1310		nm	Single-mode variant
			840		nm	Multi-mode variant
4.1.20	RX input Total Jitter			0.48	UI	@ BER = 10^{-12}, OMA = 90 µW GBTIA spec. 40ps
4.1.21	RX input Deterministic Jitter			0.28	UI	OMA = 90 µW
4.1.22	RX Sensitivity			29	µW	Single-mode fibre variant Wavelength = 1310 nm BER = 10^{-12} start of life (-15.4 dBm)
				49	µW	Multi-mode fibre variant Wavelength = 850 nm BER = 10^{-12} start of life (-13.1 dBm)

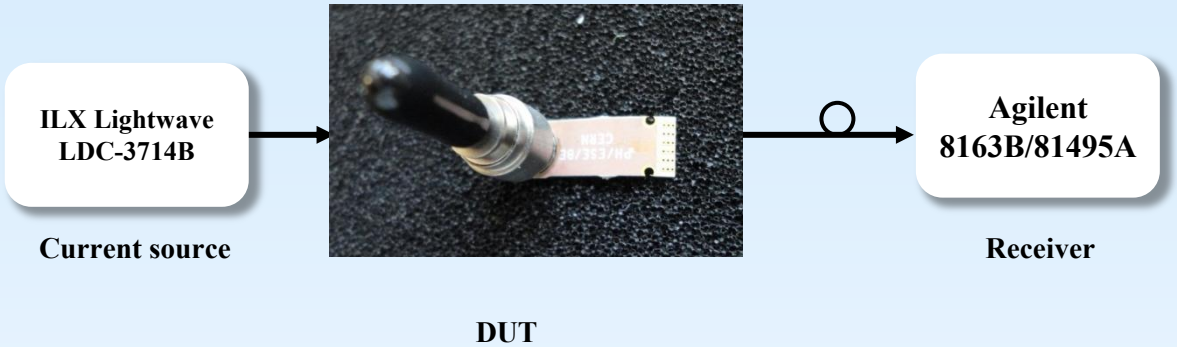
Example: specifications of the optical parts

Testing

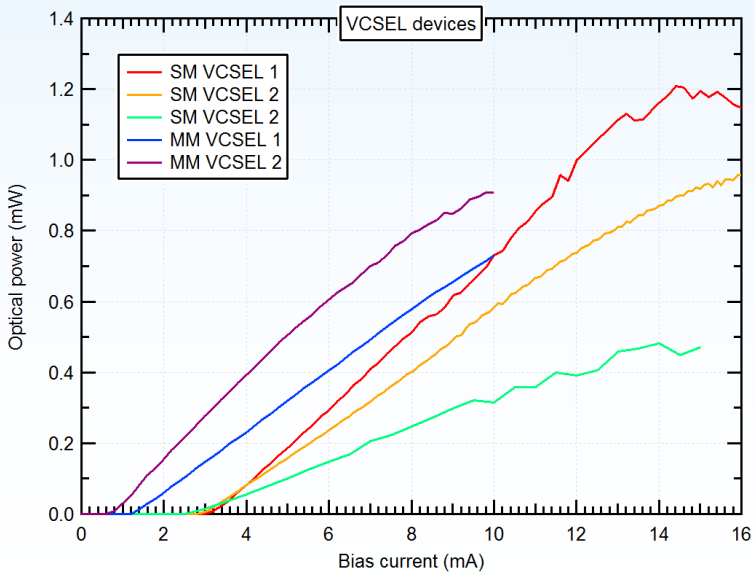


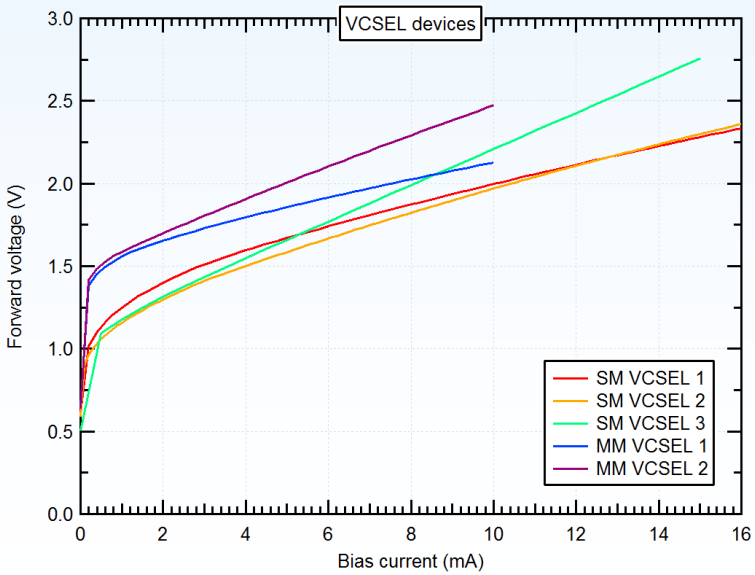
Radiation tolerance test:
Jan Troska et al. *"Single-Event Upset testing of the Versatile Transceiver "*
See poster #133

TOSA Tests – LIV curve



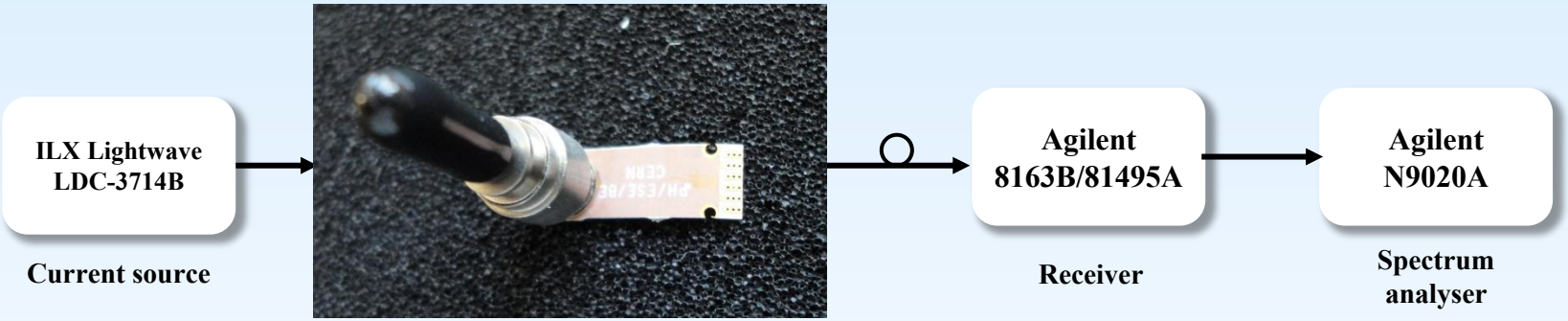
- Verify static characteristics of the laser
- Measure threshold current and the slope efficiency

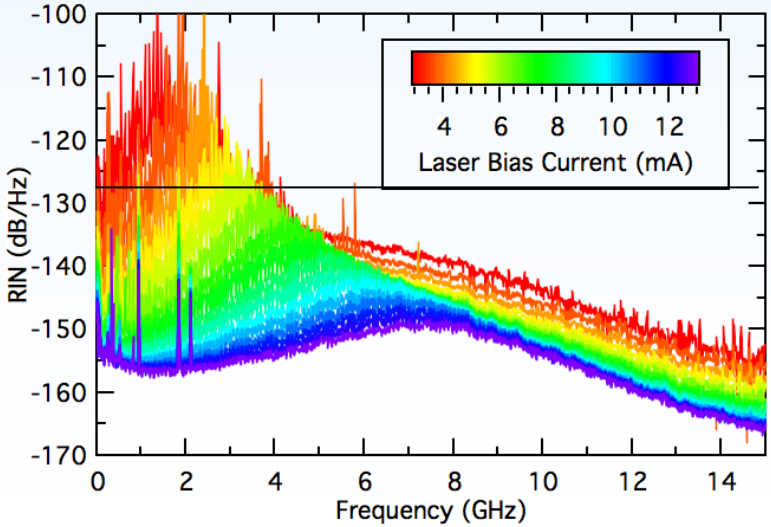


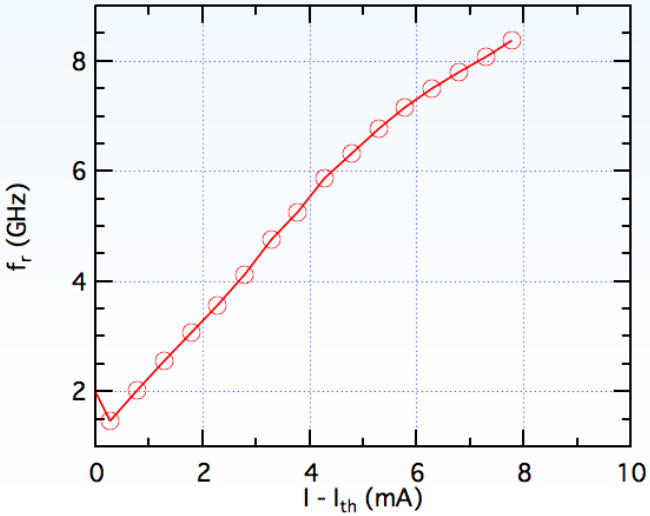


TOSA Tests – Relative Intensity Noise

- By measuring the intrinsic noise of the DC-biased laser we can extract important device parameters

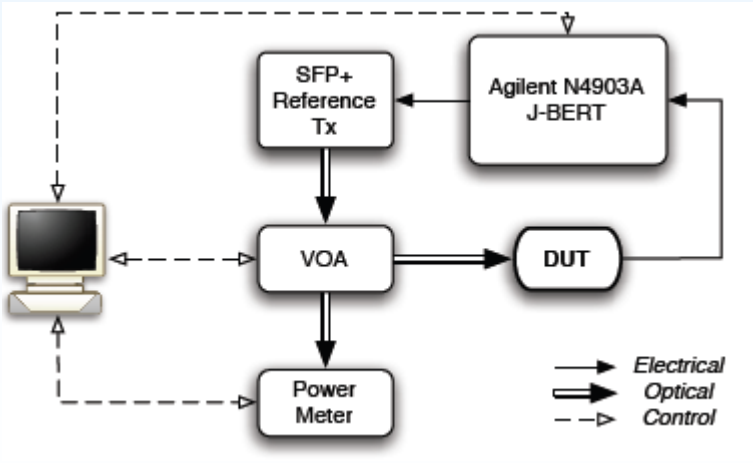


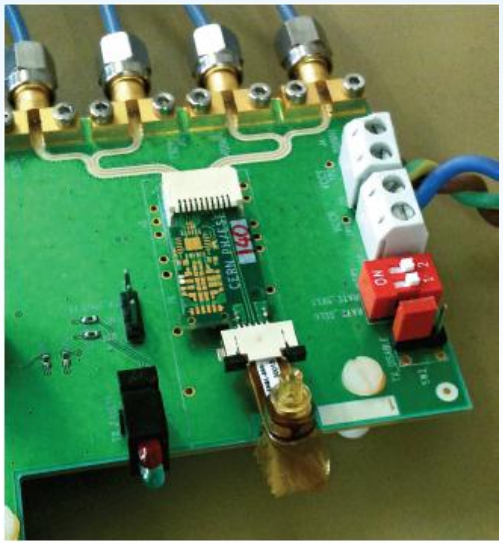




GBTIA ROSA

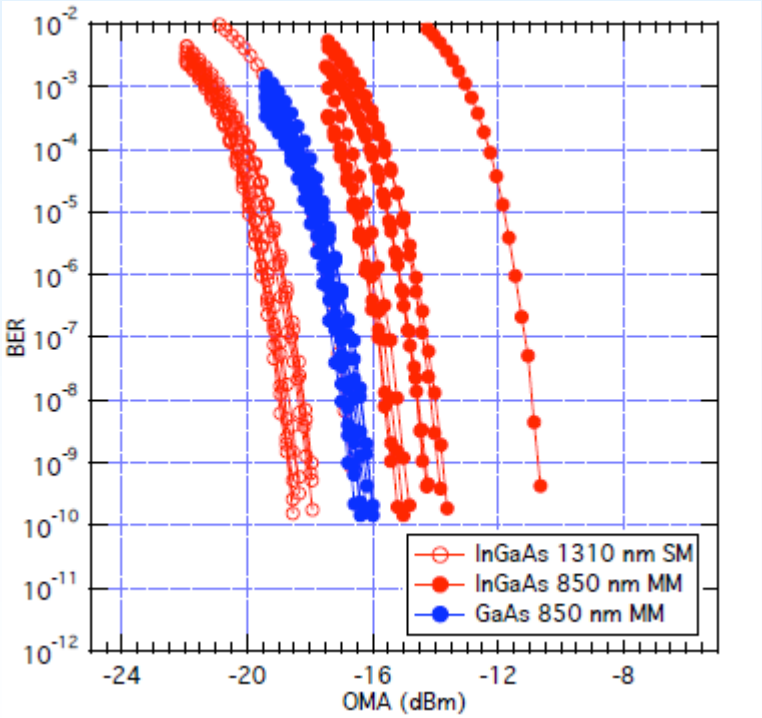
- GBTIA was assembled by commercial partner with 2 PIN photodiode types
  - InGaAs, 60 um with AR coating for 1310 SM and 850 MM operation
  - GaAs, 70 um for 850 MM
- We tested 10 devices of each type at 4.8 Gb/s

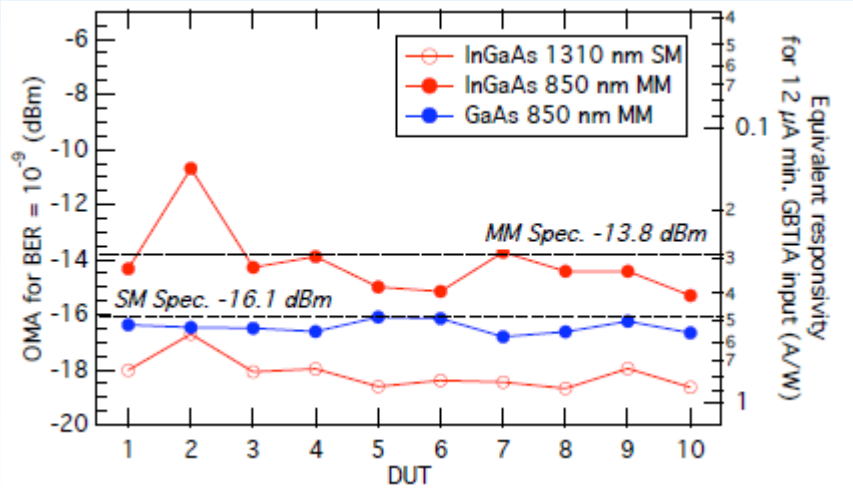




GBTIA ROSA

- 60 um InGaAs meets requirements at 1310 nm with SMF
- 60 um InGaAs marginally meets requirements at 850 nm with MMF
- 70 um GaAs meets requirements at 850 nm with MMF

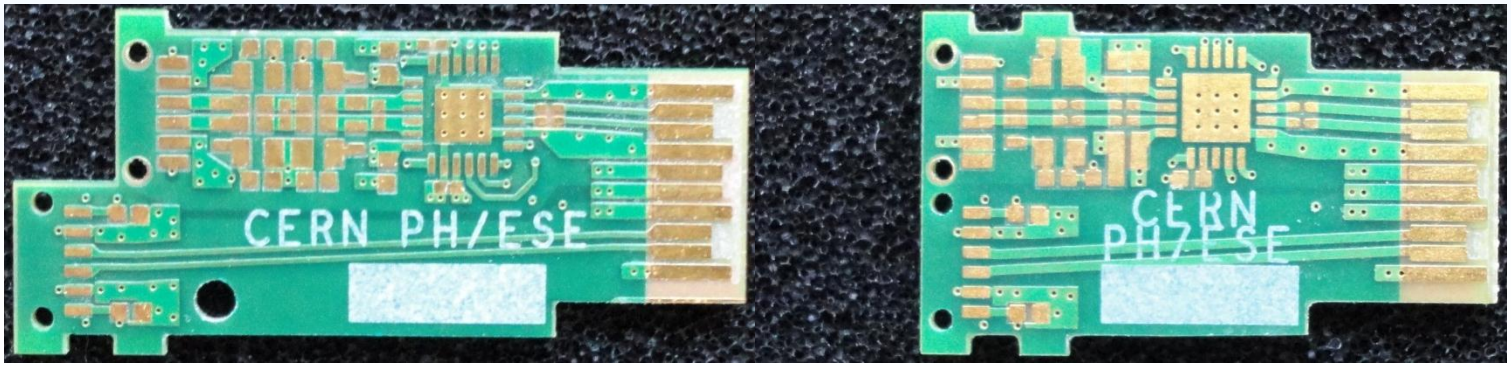




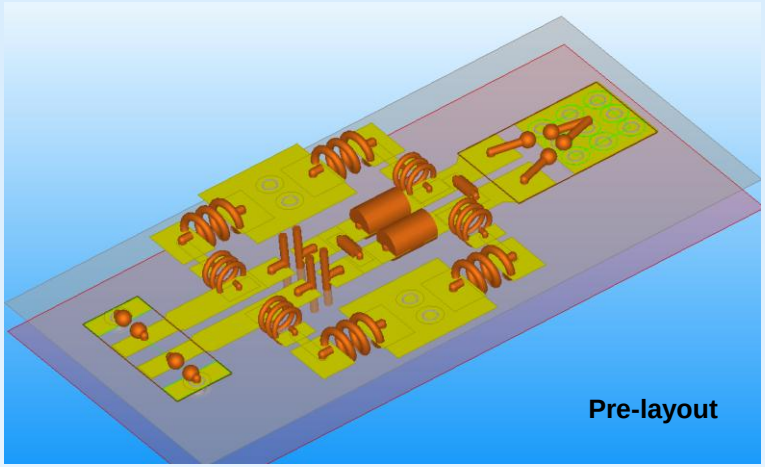
Printed Circuit Board Design

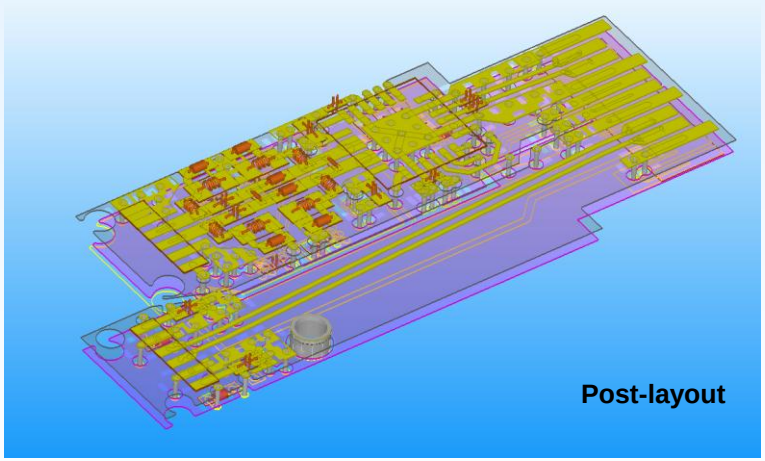
- Different VTRx versions require different boards
  - Commercial laser driver + edge emitter laser
  - Commercial laser driver + VCSEL
  - GBLD ASIC + edge emitter laser
  - GBLD ASIC + VCSEL
  - VTTx (2 x VCSEL)
- Manufacturing in CERN and in an external company
  - No major issues

Commercial driver + Edge Emitter Laser **Commercial driver + VCSEL**



Printed Circuit Board Simulation

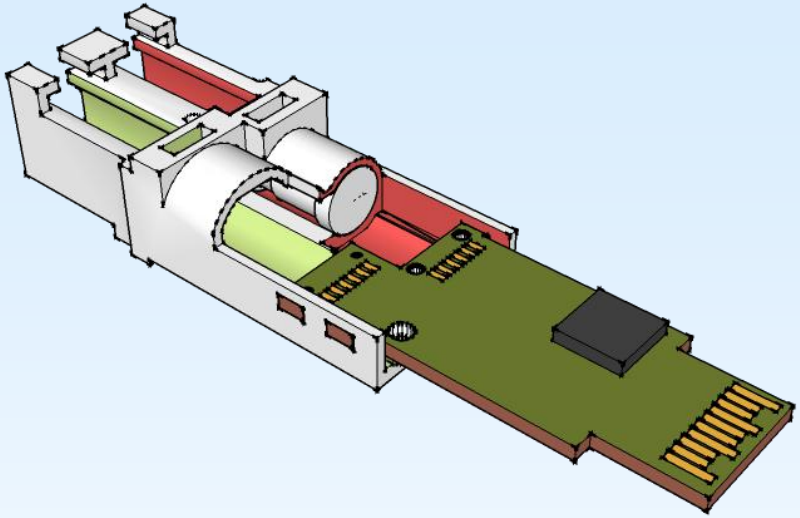


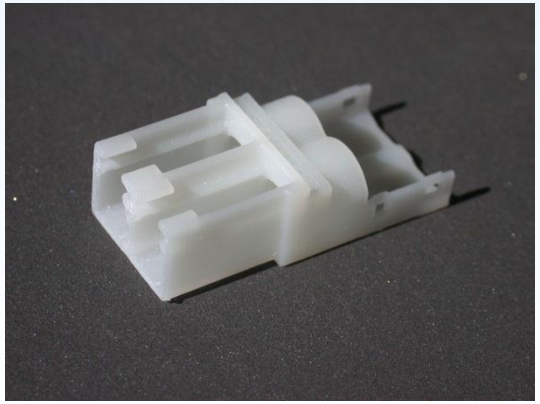


- Optimizing layout using simulator tools (pre-layout)
- Design verification (post-layout)
- ASIC designers can use PCB model for more realistic simulations
- Difficulties: still lacking good models of laser drivers and VCSELs

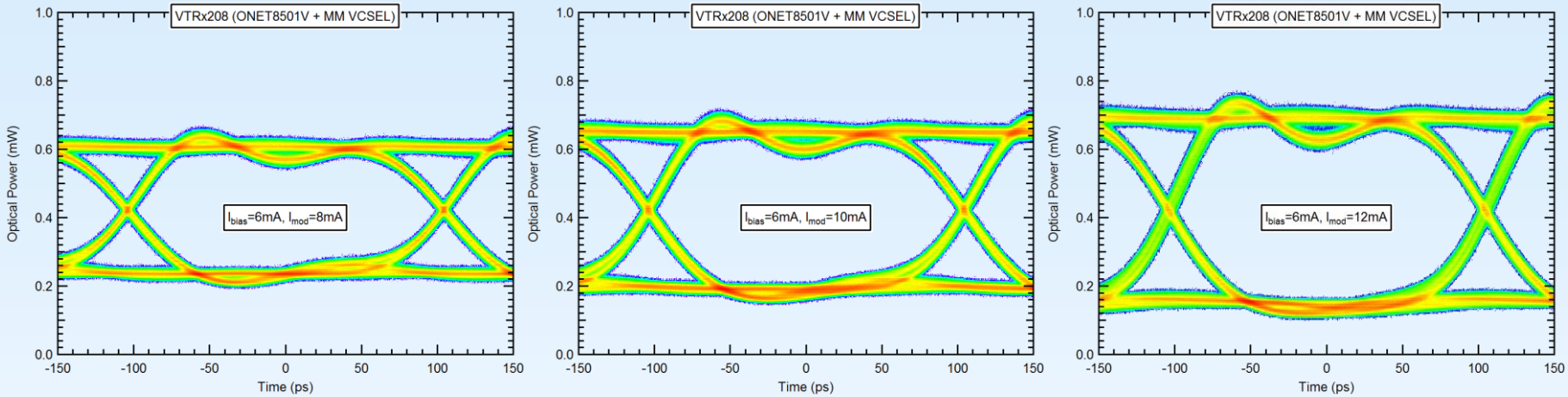
Latch Design

- Provides mechanical support for PCB, TOSA and ROSA
- Ensures good optical connection to/from TOSA/ROSA and LC optical connector
- Prototypes made using 3D prototyping techniques
  - Easy to make variants for different TOSA/ROSA dimensions
  - Radiation tolerance of material used to be proven
    - Also investigating alternative materials & processes





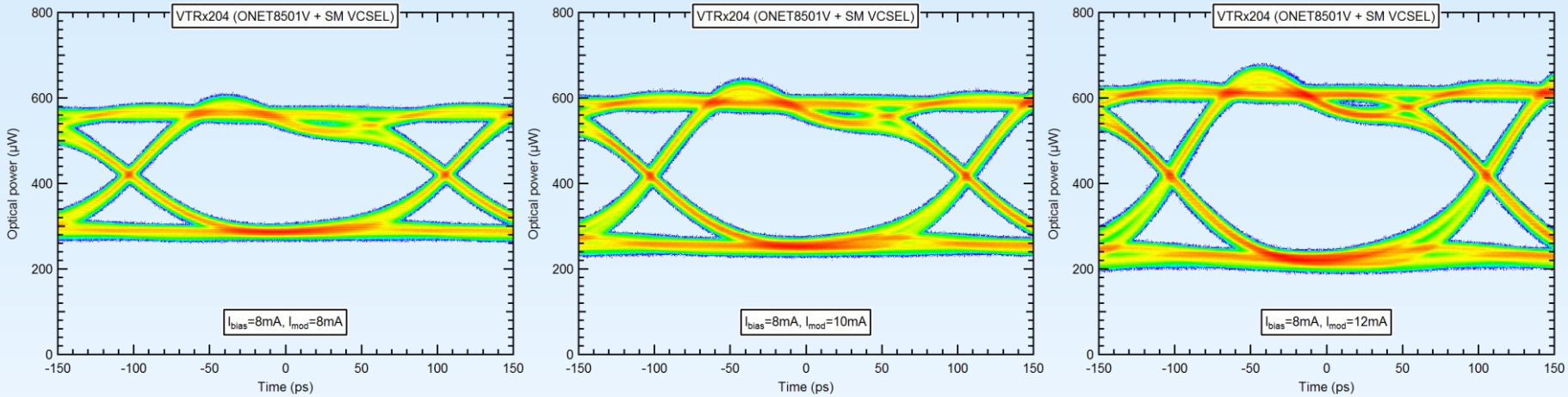
VTRx Performance – ONET8501V + MM VCSEL



Parameter	Normalization	8mA	10mA	12mA
OMA	OMA/300uW	1.19	1.48	1.76
Eye Height	Eye Height/(0.6*OMA)	1.24	1.25	1.26
ER	ER/3	1.33	1.76	2.31
$1/T_r$	$(1/T_r)/(1/70ps)$	1.73	1.70	1.88
$1/T_f$	$(1/T_f)/(1/70ps)$	1.59	1.52	1.45
$1/T_j$	$(1/T_j)/(1/0.25UI)$	3.27	3.39	3.28
$1/D_j$	$(1/D_j)/(1/0.12UI)$	22.88	12.93	6.60
Note: Bit rate = 4.8 Gb/s, UI = 208 ps				

Normalized eye diagram parameters. Higher values represent better performance. Values smaller than 1 mean that the spec is violated.

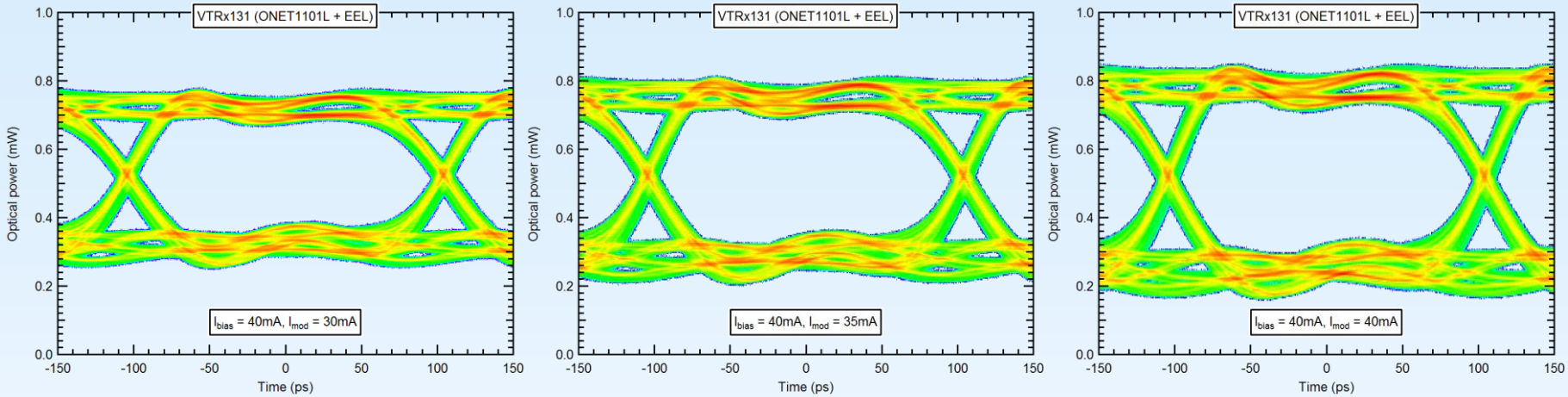
VTRx Performance – ONET8501V + SM VCSEL



Parameter	Normalization	8mA	10mA	12mA
OMA	OMA/300uW	0.88	1.07	1.25
Eye Height	Eye Height/(0.6*OMA)	1.26	1.28	1.27
ER	ER/3	0.95	1.18	1.43
$1/T_r$	$(1/T_r)/(1/70ps)$	1.38	1.38	1.43
$1/T_f$	$(1/T_f)/(1/70ps)$	1.05	1.02	1.06
$1/T_j$	$(1/T_j)/(1/0.25UI)$	2.07	2.12	1.88
$1/D_j$	$(1/D_j)/(1/0.12UI)$	6.49	5.22	2.78
Note: Bit rate = 4.8 Gb/s, UI = 208 ps				

Normalized eye diagram parameters. Higher values represent better performance. Values smaller than 1 mean that the spec is violated.

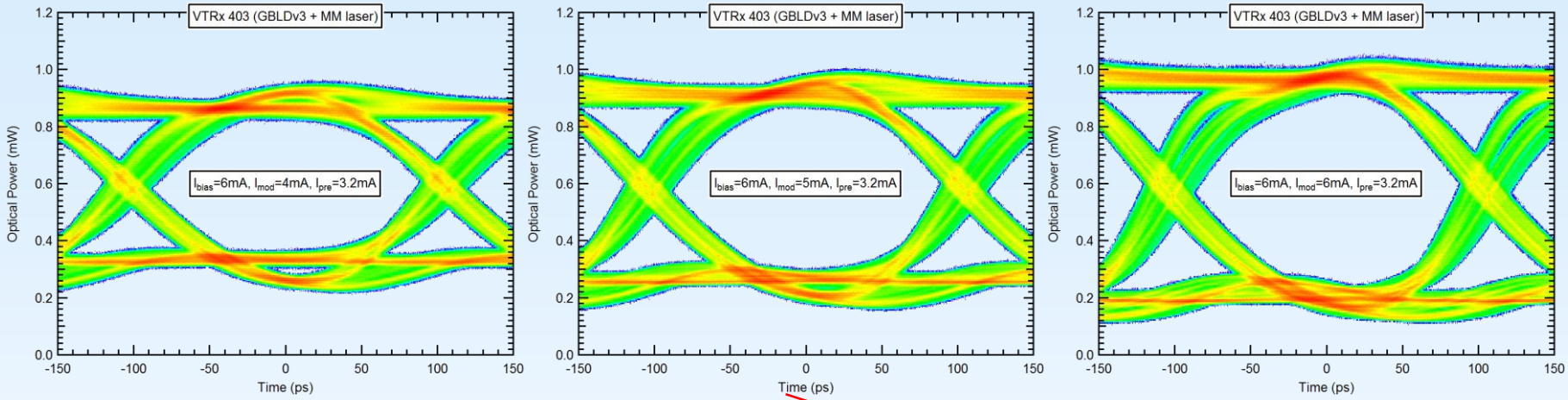
VTRx Performance – ONET1101L + EEL



Parameter	Normalization	30mA	35mA	40mA
OMA	OMA/300uW	1.27	1.49	1.70
Eye Height	Eye Height/(0.6*OMA)	1.05	1.05	1.06
ER	ER/3	1.09	1.30	1.56
$1/T_r$	$(1/T_r)/(1/70ps)$	2.13	2.14	2.17
$1/T_f$	$(1/T_f)/(1/70ps)$	1.81	1.78	1.74
$1/T_j$	$(1/T_j)/(1/0.25UI)$	2.81	2.91	2.99
$1/D_j$	$(1/D_j)/(1/0.12UI)$	2.77	2.63	2.87
Note: Bit rate = 4.8 Gb/s, UI = 208 ps				

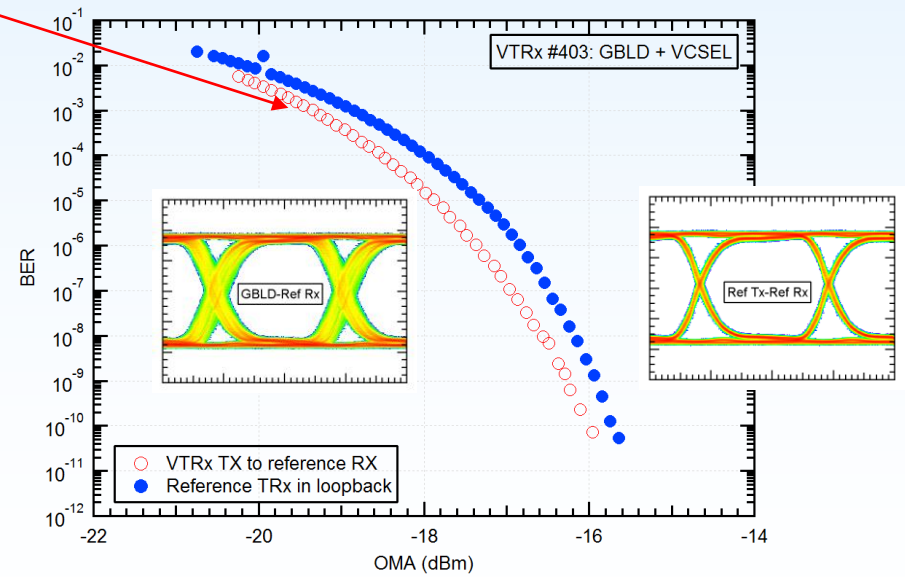
Normalized eye diagram parameters. Higher values represent better performance. Values smaller than 1 mean that the spec is violated.

VTRx Performance – GBLDv3 + MM VCSEL

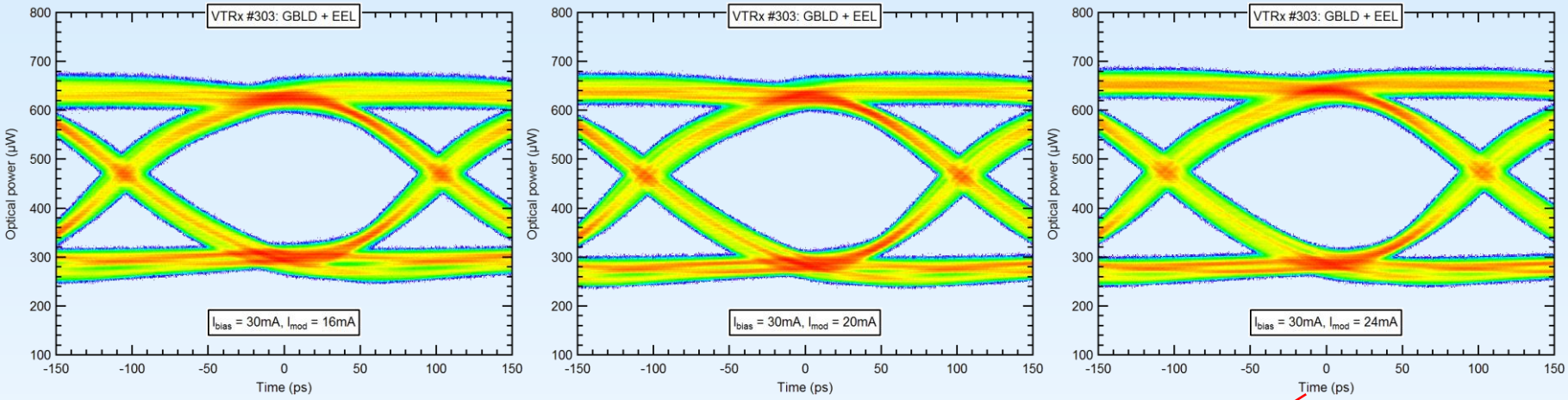


Parameter	Normalization	4mA	5mA	6mA
OMA	OMA/300uW	1.96	2.27	2.55
Eye Height	Eye Height/(0.6*OMA)	1.09	1.26	1.35
ER	ER/3	1.54	1.91	2.25
$1/T_r$	$(1/T_r)/(1/70ps)$	1.10	1.18	1.63
$1/T_f$	$(1/T_f)/(1/70ps)$	0.92	0.90	0.87
$1/T_j$	$(1/T_j)/(1/0.25UI)$	1.21	1.26	1.18
$1/D_j$	$(1/D_j)/(1/0.12UI)$	0.93	0.97	0.90
Note: Bit rate = 4.8 Gb/s, UI = 208 ps				

Normalized eye diagram parameters. Higher values represent better performance. Values smaller than 1 mean that the spec is violated.

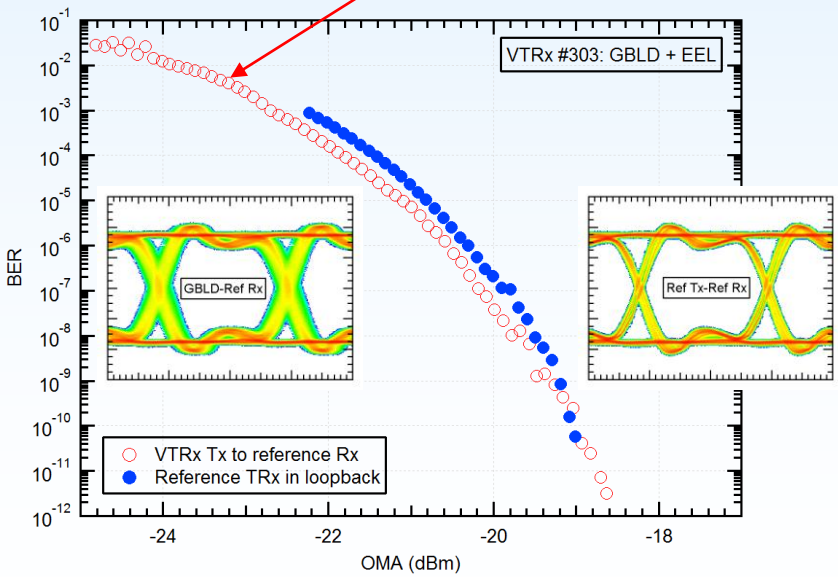


VTRx Performance – GBLDv3 + EEL



Parameter	Normalization	16mA	20mA	24mA
OMA	OMA/300uW	1.08	1.13	1.17
Eye Height	Eye Height/(0.6*OMA)	1.29	1.30	1.29
ER	ER/3	1.07	1.13	1.14
$1/T_r$	$(1/T_r)/(1/70ps)$	0.89	0.86	0.83
$1/T_f$	$(1/T_f)/(1/70ps)$	0.80	0.77	0.75
$1/T_j$	$(1/T_j)/(1/0.25UI)$	1.01	0.98	0.96
$1/D_j$	$(1/D_j)/(1/0.12UI)$	1.03	0.86	0.86
Note: Bit rate = 4.8 Gb/s, UI = 208 ps				

Normalized eye diagram parameters. Higher values represent better performance. Values smaller than 1 mean that the spec is violated.



Future work

- Investigate options
  - SM VCSEL vs EEL
  - GaAs vs InGaAs PIN for MM applications
- Environmental tests
  - Repeat magnetic field tests
  - Conduct EMC/EMI tests
  - Thermal tests
- Work on LC latch variants
- Finish and test dual transmitter design (VTTx)
- Integrate new generations of ASICs into the design

Conclusion

- Successfully tested TOSA and ROSA components
  - Identified candidate components for all flavors
- PCBs are ready for almost all variants
  - Dual transmitter version will be ready soon
- Designed, manufactured and tested several VTRx prototypes
  - Good performance has been demonstrated
- Boards are available for system integrators
- Ready to move on to Phase III

TOSA Tests – Relative Intensity Noise

Versatile Link

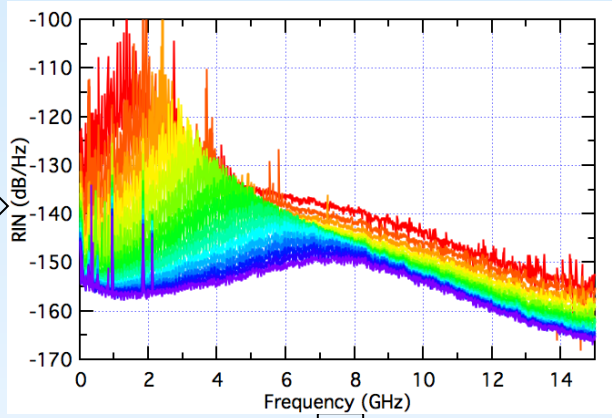
Spectral data

Correction: removal of thermal and shot noise

$$RIN_{Laser}(\omega) = 10 \cdot \log\left(\frac{N_{System}(\omega)}{P_{Electrical}} - \frac{N_{Thermal}(\omega)}{P_{Electrical}} - \frac{N_{Shot}}{P_{Electrical}}\right) - 10 \cdot \log(RBW) \ \ (dB/Hz)$$

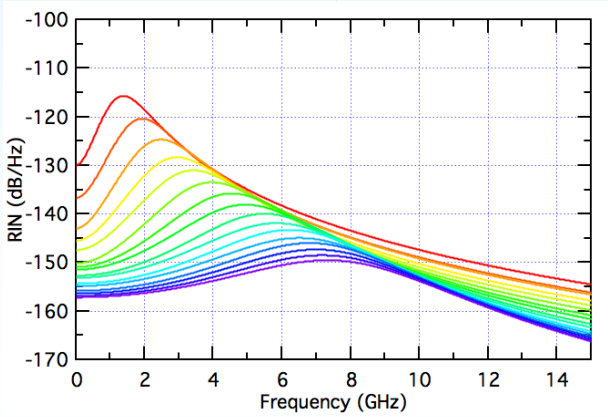
$$P_{Electrical} = \frac{(r_V \cdot P_{Optical})^2}{R_L}$$

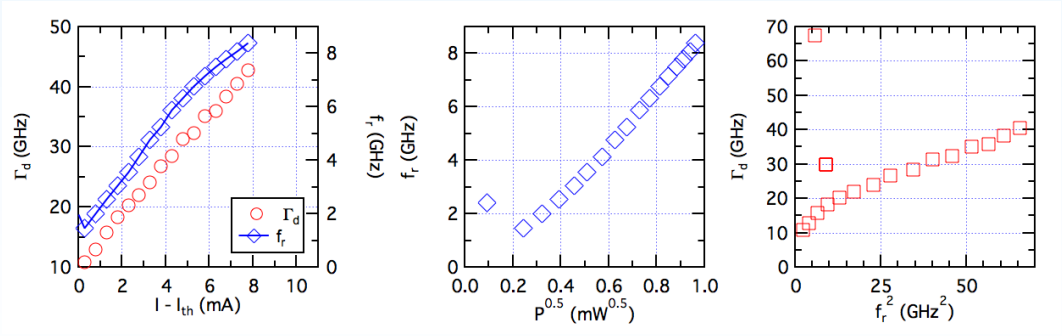
$$\frac{N_{Shot}}{P_{Electrical}} = \frac{2 \cdot q}{i} = \frac{2 \cdot q}{r \cdot P_{Optical}} = \frac{2 \cdot q \cdot G_V \cdot R_L}{r_V \cdot P_{Optical}}$$



Fitting

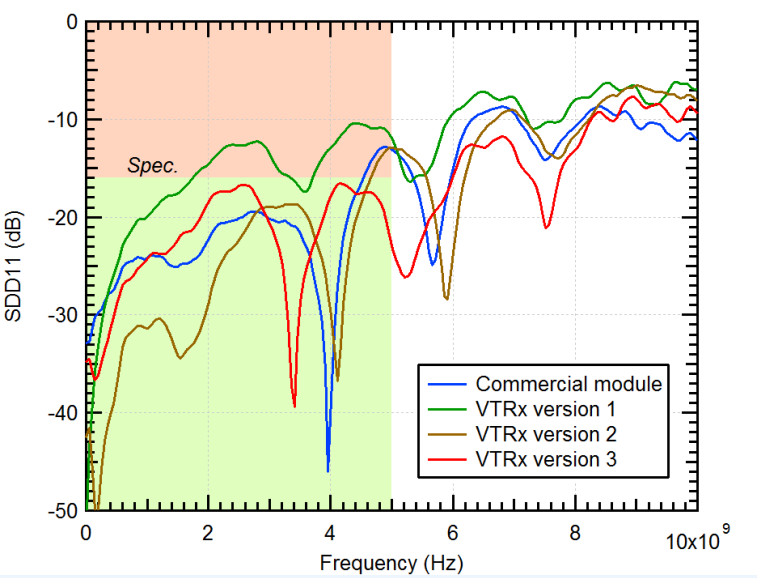
$$RIN(f) = \frac{A + B(2\pi f)^2}{16\pi^4(f^2 - f_r^2) + (2\pi f)^2 \Gamma_d^2}$$



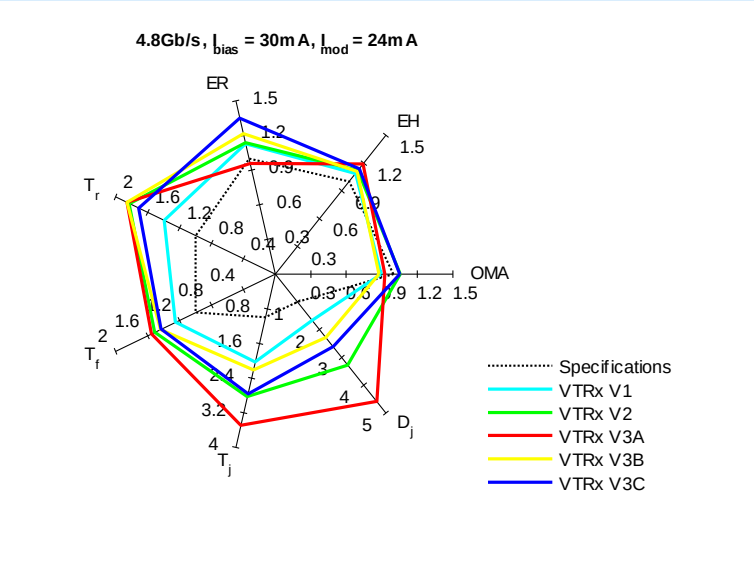


Extracted parameters: f_r and Γ_d

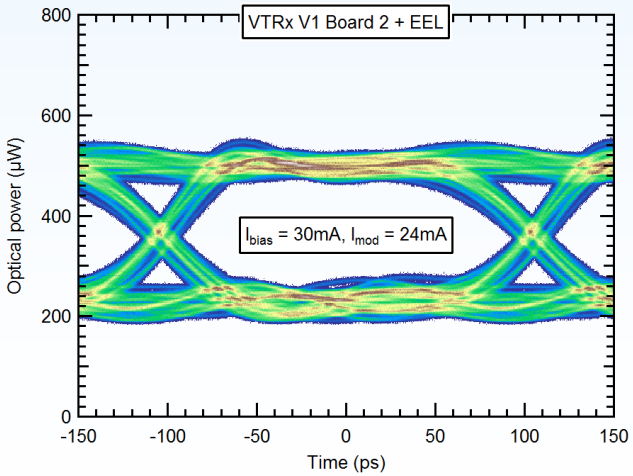
Printed Circuit Board Performance

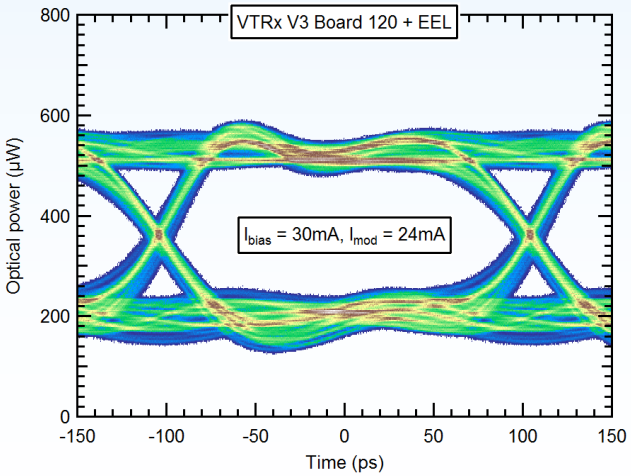


VTRx input return loss

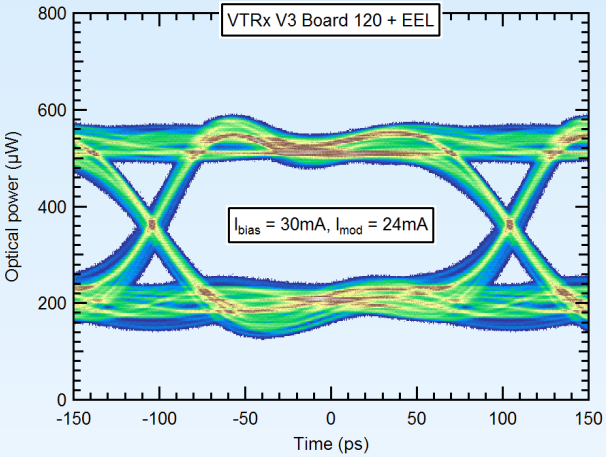


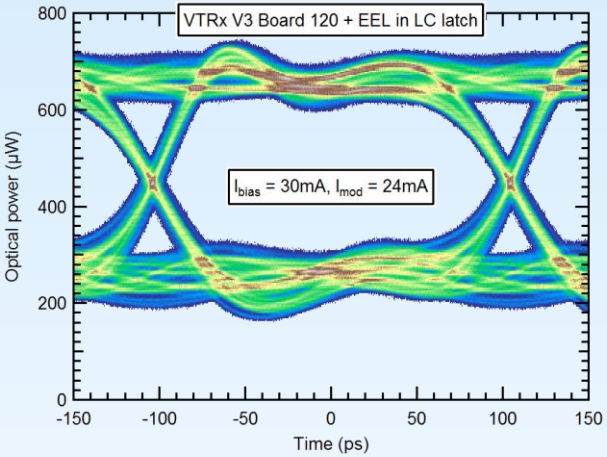
VTRx performance comparison

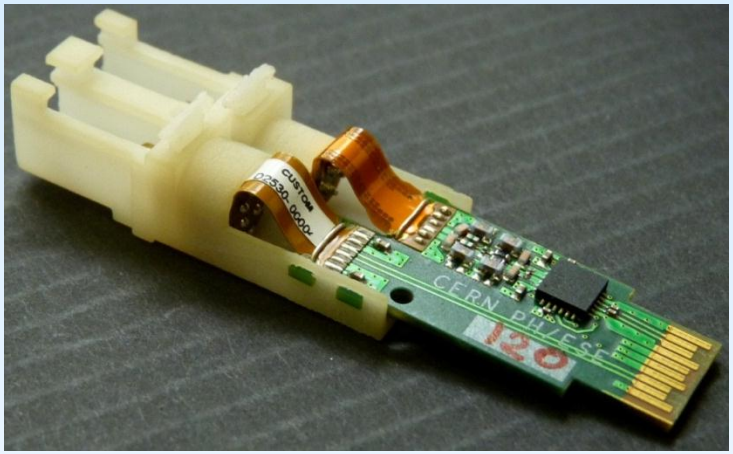




Latch Performance



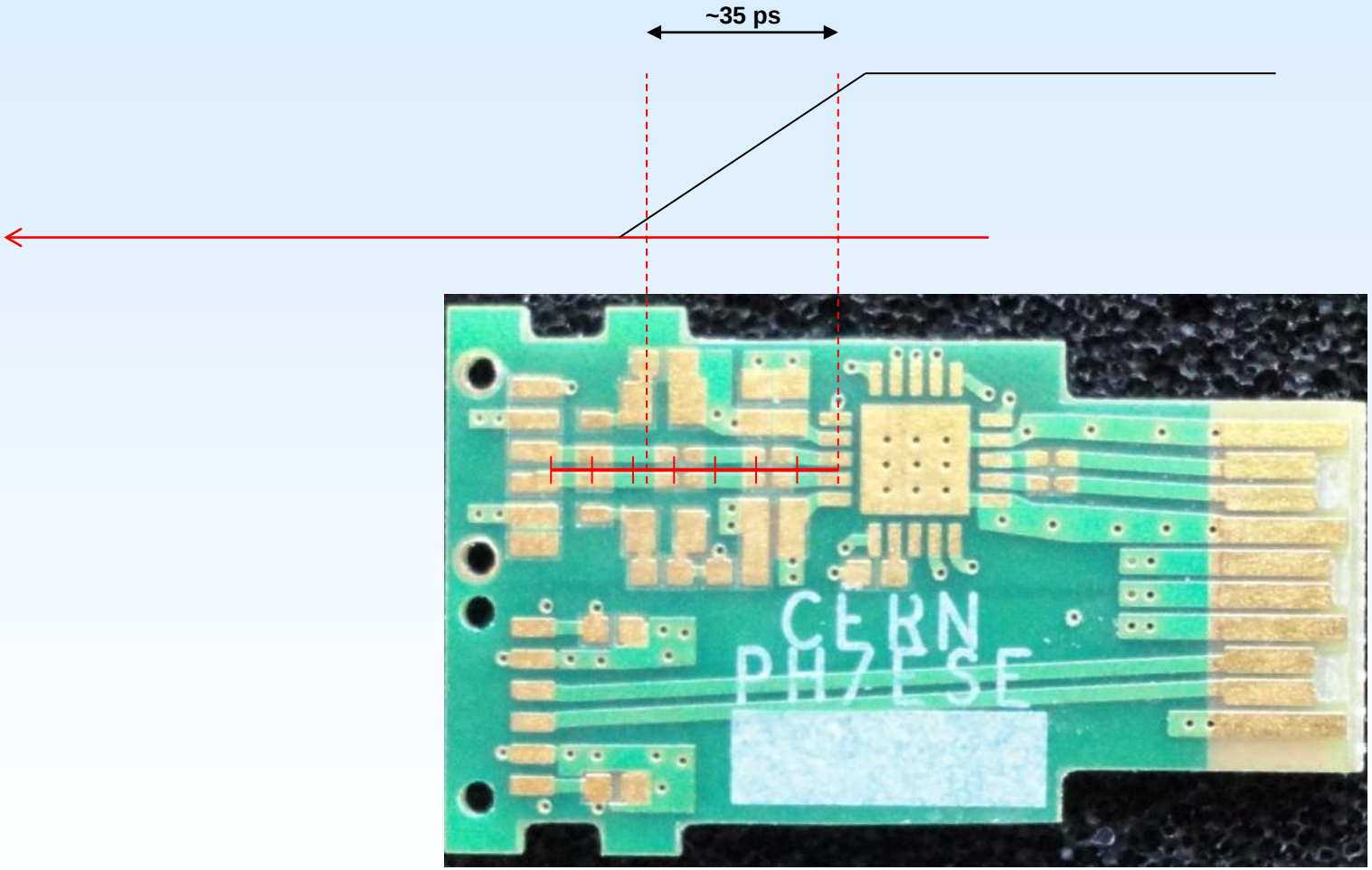




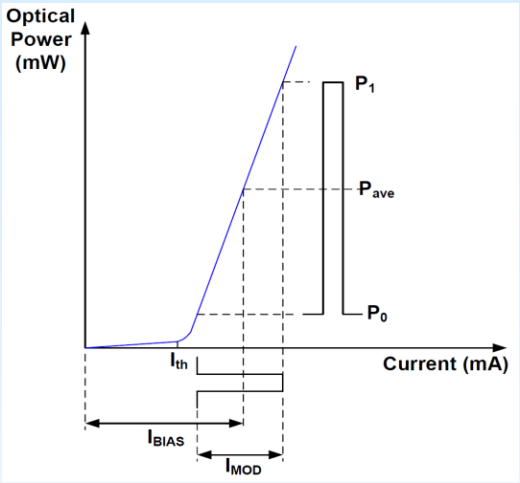
Parameter	Normalization	w/o latch	/w latch
OMA	OMA/300uW	1.05	1.31
Eye Height	Eye Height/(0.6*OMA)	1.14	1.12
ER	ER/3	1.35	1.32
$1/T_r$	$(1/T_r)/(1/70ps)$	1.99	2.08
$1/T_f$	$(1/T_f)/(1/70ps)$	1.66	1.65
$1/T_j$	$(1/T_j)/(1/0.25UI)$	2.77	3.29
$1/D_j$	$(1/D_j)/(1/0.12UI)$	2.61	4.01
Note: Bit rate = 4.8 Gb/s, UI = 208 ps			

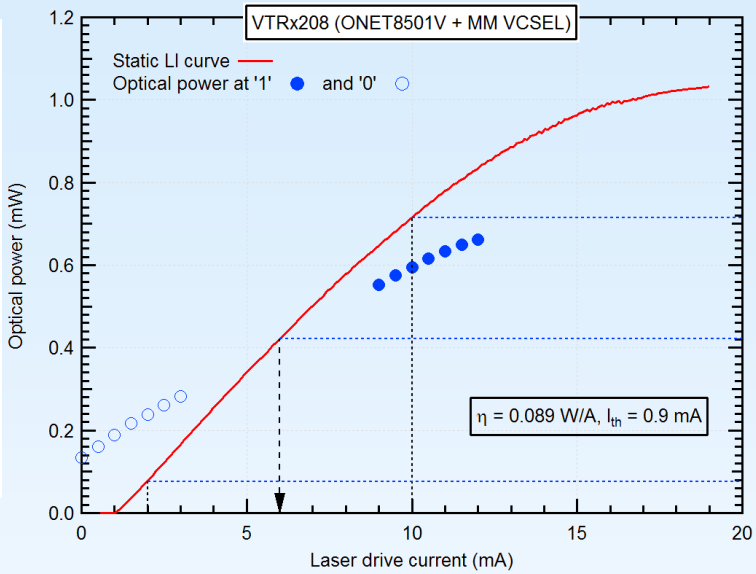
Normalized eye diagram parameters. Higher values represent better performance. Values smaller than 1 mean that the spec is violated.

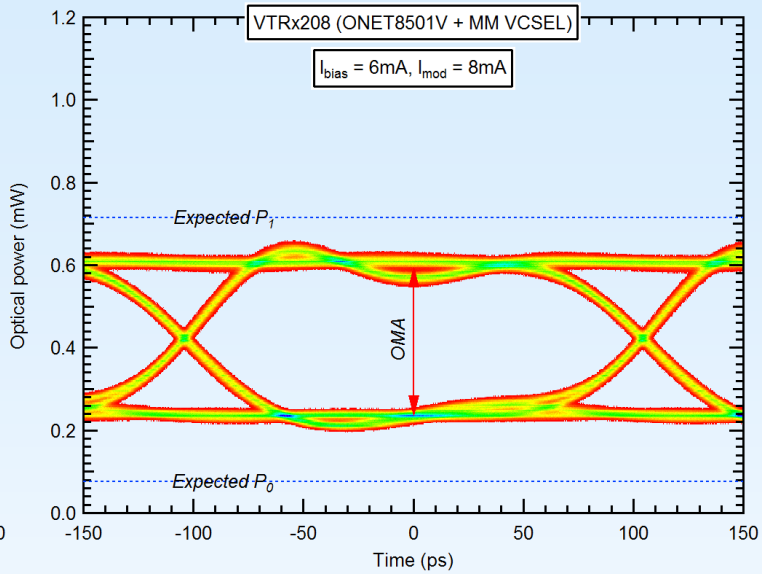
Short ? It depends …



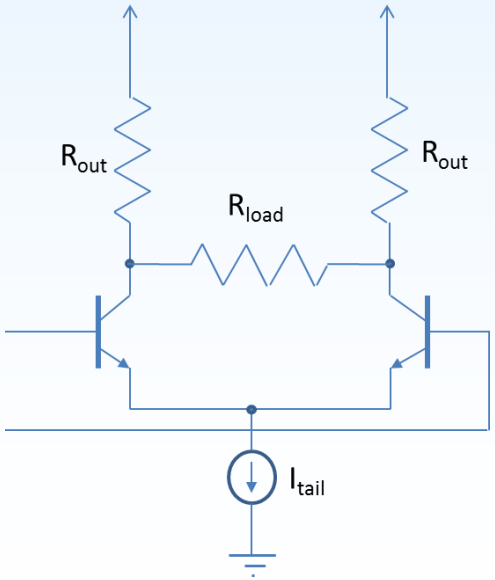
Laser Modulation vs OMA







$$\text{Expected } OMA = \eta \cdot I_{mod}$$



Example: assuming R_{out} = 50, R_{load} = 70, the current divider in the collector results in ±0.29xI_{tail} through R_{load}