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 Development Status

TWEPP 2011 Versatile Transceiver - Development Status
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

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

Example: specifications of the optical parts

TWEPP 2011
Testing

Static: LIV and RIN
Dynamic test as full module

Dynamic: BER-> Sensitivity

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

**Diagram: Versatile Transceiver - Development Status**

- **DUT (Device Under Test)**
  - Laser Bias Current (mA)
  - Frequency (GHz)
  - RIN (Relative Intensity Noise) (dB/Hz)

**Equipment:**
- ILX Lightwave LDC-3714B
- Agilent 8163B/81495A
- Agilent N9020A

**Notes:**
- TOSA Tests – Relative Intensity Noise
- TWEPP 2011
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
- 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
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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normalization</th>
<th>8mA</th>
<th>10mA</th>
<th>12mA</th>
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</thead>
<tbody>
<tr>
<td>OMA</td>
<td>OMA/300uW</td>
<td>1.19</td>
<td>1.48</td>
<td>1.76</td>
</tr>
<tr>
<td>Eye Height</td>
<td>Eye Height/(0.6*OMA)</td>
<td>1.24</td>
<td>1.25</td>
<td>1.26</td>
</tr>
<tr>
<td>ER</td>
<td>ER/3</td>
<td>1.33</td>
<td>1.76</td>
<td>2.31</td>
</tr>
<tr>
<td>1/T_r</td>
<td>(1/T_r)/(1/70ps)</td>
<td>1.73</td>
<td>1.70</td>
<td>1.88</td>
</tr>
<tr>
<td>1/T_f</td>
<td>(1/T_f)/(1/70ps)</td>
<td>1.59</td>
<td>1.52</td>
<td>1.45</td>
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<tr>
<td>1/T_j</td>
<td>(1/T_j)/(1/0.25UI)</td>
<td>3.27</td>
<td>3.39</td>
<td>3.28</td>
</tr>
<tr>
<td>1/D_j</td>
<td>(1/D_j)/(1/0.12UI)</td>
<td>22.88</td>
<td>12.93</td>
<td>6.60</td>
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</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normalization</th>
<th>8mA</th>
<th>10mA</th>
<th>12mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMA</td>
<td>OMA/300µW</td>
<td>0.88</td>
<td>1.07</td>
<td>1.25</td>
</tr>
<tr>
<td>Eye Height</td>
<td>Eye Height/(0.6*OMA)</td>
<td>1.26</td>
<td>1.28</td>
<td>1.27</td>
</tr>
<tr>
<td>ER</td>
<td>ER/3</td>
<td>0.95</td>
<td>1.18</td>
<td>1.43</td>
</tr>
<tr>
<td>1/T_r</td>
<td>(1/T_r)/(1/70ps)</td>
<td>1.38</td>
<td>1.38</td>
<td>1.43</td>
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<tr>
<td>1/T_f</td>
<td>(1/T_f)/(1/70ps)</td>
<td>1.05</td>
<td>1.02</td>
<td>1.06</td>
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<tr>
<td>1/T_j</td>
<td>(1/T_j)/(1/0.25UI)</td>
<td>2.07</td>
<td>2.12</td>
<td>1.88</td>
</tr>
<tr>
<td>1/D_j</td>
<td>(1/D_j)/(1/0.12UI)</td>
<td>6.49</td>
<td>5.22</td>
<td>2.78</td>
</tr>
</tbody>
</table>

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/300μW | 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/Tₚ | (1/Tₚ)/(1/70ps) | 2.13 | 2.14 | 2.17
1/Tᵣ | (1/Tᵣ)/(1/70ps) | 1.81 | 1.78 | 1.74
1/Tᵢ | (1/Tᵢ)/(1/0.25UI) | 2.81 | 2.91 | 2.99
1/Dᵢ | (1/Dᵢ)/(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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normalization</th>
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<th>5mA</th>
<th>6mA</th>
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<tbody>
<tr>
<td>OMA</td>
<td>OMA/300μW</td>
<td>1.96</td>
<td>2.27</td>
<td>2.55</td>
</tr>
<tr>
<td>Eye Height</td>
<td>Eye Height/(0.6*OMA)</td>
<td>1.09</td>
<td>1.26</td>
<td>1.35</td>
</tr>
<tr>
<td>ER</td>
<td>ER/3</td>
<td>1.54</td>
<td>1.91</td>
<td>2.25</td>
</tr>
<tr>
<td>$1/T_r$</td>
<td>$(1/T_r)/(1/70ps)$</td>
<td>1.10</td>
<td>1.18</td>
<td>1.63</td>
</tr>
<tr>
<td>$1/T_f$</td>
<td>$(1/T_f)/(1/70ps)$</td>
<td>0.92</td>
<td>0.90</td>
<td>0.87</td>
</tr>
<tr>
<td>$1/D_j$</td>
<td>$(1/D_j)/(1/0.25UI)$</td>
<td>1.21</td>
<td>1.26</td>
<td>1.18</td>
</tr>
<tr>
<td>$1/D_j$</td>
<td>$(1/D_j)/(1/0.12UI)$</td>
<td>0.93</td>
<td>0.97</td>
<td>0.90</td>
</tr>
</tbody>
</table>

*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**

![Eye Diagrams](image)

### Parameter Normalization

<table>
<thead>
<tr>
<th></th>
<th>Normalization</th>
<th>16mA</th>
<th>20mA</th>
<th>24mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMA</td>
<td>OMA/300uW</td>
<td>1.08</td>
<td>1.13</td>
<td>1.17</td>
</tr>
<tr>
<td>Eye Height</td>
<td>Eye Height/(0.6*OMA)</td>
<td>1.29</td>
<td>1.30</td>
<td>1.29</td>
</tr>
<tr>
<td>ER</td>
<td>ER/3</td>
<td>1.07</td>
<td>1.13</td>
<td>1.14</td>
</tr>
<tr>
<td>$1/T_r$</td>
<td>$(1/T_r)/(1/70ps)$</td>
<td>0.89</td>
<td>0.86</td>
<td>0.83</td>
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<tr>
<td>$1/T_f$</td>
<td>$(1/T_f)/(1/70ps)$</td>
<td>0.80</td>
<td>0.77</td>
<td>0.75</td>
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<tr>
<td>$1/T_j$</td>
<td>$(1/T_j)/(1/0.25UI)$</td>
<td>1.01</td>
<td>0.98</td>
<td>0.96</td>
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<tr>
<td>$1/D_j$</td>
<td>$(1/D_j)/(1/0.12UI)$</td>
<td>1.03</td>
<td>0.86</td>
<td>0.86</td>
</tr>
</tbody>
</table>

**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

Correction: removal of thermal and shot noise

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

\[ P_{\text{Electrical}} = \frac{r V \cdot P_{\text{Optical}}}{2} \]

\[ N_{\text{Shot}} \frac{2 \cdot q}{i} = 2 \cdot q \cdot \frac{r \cdot P_{\text{Optical}}}{r V \cdot P_{\text{Optical}}} \]

Spectral data

Fitting

\[ RIN(f) = \frac{A + B(2\pi f)^2}{16\pi^4(f^2 - f_i^2) + (2\pi f)^2 \Gamma_d^2} \]

Extracted parameters: \( f_i \) and \( \Gamma_d \)
Printed Circuit Board Performance

VTRx input return loss

VTRx performance comparison
Latch Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normalization</th>
<th>w/o latch</th>
<th>/w latch</th>
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<tbody>
<tr>
<td>OMA</td>
<td>OMA/300uW</td>
<td>1.05</td>
<td>1.31</td>
</tr>
<tr>
<td>Eye Height</td>
<td>Eye Height/(0.6*OMA)</td>
<td>1.14</td>
<td>1.12</td>
</tr>
<tr>
<td>ER</td>
<td>ER/3</td>
<td>1.35</td>
<td>1.32</td>
</tr>
<tr>
<td>$1/T_r$</td>
<td>$(1/T_r)/(1/70ps)$</td>
<td>1.99</td>
<td>2.08</td>
</tr>
<tr>
<td>$1/T_f$</td>
<td>$(1/T_f)/(1/70ps)$</td>
<td>1.66</td>
<td>1.65</td>
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<tr>
<td>$1/T_j$</td>
<td>$(1/T_j)/(1/0.25UI)$</td>
<td>2.77</td>
<td>3.29</td>
</tr>
<tr>
<td>$1/D_j$</td>
<td>$(1/D_j)/(1/0.12UI)$</td>
<td>2.61</td>
<td>4.01</td>
</tr>
</tbody>
</table>

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 …

~35 ps
Laser Modulation vs OMA

Example: assuming $R_{\text{out}} = 50$, $R_{\text{load}} = 70$, the current divider in the collector results in $\pm 0.29 \times I_{\text{tail}}$ through $R_{\text{load}}$

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