coherent optical transceivers

current capabilities and future possibilities
100G ecosystem limits ...

- ratio of power consumption to formfactor
- focus on inner datacenter links
- variation of diverse hardware

CFP
CFP2
CFP4
QSFP28
CPAK
Coherent optical transceivers
... sorted now with 400G

DWDM transponder card

DSP
28nm

pluggable QSFP-DD

Coherent optical transceivers
Direct Detection Transceiver limits

With higher frequencies -> harder for Photodiodes to detect

Missed Opportunity: Light has more Properties
Direct Detection Transceiver limits

With **higher** frequencies -> harder for Photodiodes to detect

Missed Opportunity: **Light** has more **Properties**
Direct Detection Transceiver limits

With higher frequencies -> harder for Photodiodes to detect

Missed Opportunity: **Light** has more **Properties**
Main Properties of Photonic Waves

• Besides **Amplitude**, also **Phase** and **Polarisation**
• More properties per Carrier = Higher Bandwidth
Polarisation Signal on X and Y Plane
Polarisation Signal on X and Y Plane

16-QAM Modulated Signal

Time (ns)

X

0 0.5 1 1.5 2 2.5 3 3.5

-15 -10 -5 0 5 10 15
Polarisation Signal on X and Y Plane

16-QAM Modulated Signal

Time (ns)

X

Y
Constellation Diagramm

- Quadrature Component (imag)
- In-Phase Component (real)

0 (off) and 1 (on)
Constellation Diagramm
90° phase shifted amplitude

Constellation Diagramm

- In-Phase Component (real)
- Quadrature Component (imag)
- 0010, 0110, 1110, 1010
- 0011, 0111, 1111, 1011
- 0001, 0101, 1101, 1001
- 0000, 0100, 1100, 1000

OOK
PAM4
16QAM
Coherent optical transceivers

90° phase shift

real

imaginary

30.04.2024

source: [9]
Coherent optical transceivers

90° phase shift

real

imaginary

90°

real

imaginary
Measuring Signal Quality

- **SNR** = Signal-to-Noise-Ratio
- Convenience of using decibels for **small** and **large** values
- (e)SNR vs OSNR: **electrical vs optical**
Phase and Amplitude Errors

NOTE: Polarisation Error not considered
NOKIA SR-OS and 400G ZR Transceiver

+ = terrific coherent workshop with

source: Daniel Melzer, DE-CIX

source: https://www.flexoptix.net/en/d-co164hg-2-yt.html
Nokia 7950 XRS# show port 8/1/c7

<table>
<thead>
<tr>
<th>Description</th>
<th>QSFP-DD Connector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface</td>
<td>8/1/c7</td>
</tr>
<tr>
<td>FP Number</td>
<td>2</td>
</tr>
<tr>
<td>MAC Chip Number</td>
<td>3</td>
</tr>
<tr>
<td>Breakout</td>
<td>C1-400g</td>
</tr>
<tr>
<td>RS-FEC Config Mode</td>
<td>None</td>
</tr>
</tbody>
</table>

### Transceiver Data

- **Transceiver Status**: operational
- **Transceiver Type**: QSFP-DD
- **Model Number**: 3HE16564AARA01
- **TX Laser Wavelength**: 1558.983 nm
- **Present Channel**: 23
- **Configured Chann**: 23
- **Laser Tunability**: flex-tunable
- **Config Freq (MHz)**: 0
- **Oper Freq (MHz)**: 192300000
- **Min Freq (MHz)**: 191300000
- **Max Freq (MHz)**: 196100000
- **Fine Tune Range**: 6000 MHz
- **Fine Tune Resolu**: 1 MHz
- **Supported Grids**: 100GHz 75GHz 50GHz 25GHz 12.5GHz 6.25GHz
- **Diag Capable**: yes
- **Number of Lanes**: 1
- **Connector Code**: LC
- **Vendor OUI**: 20:20:20
- **Manufacture date**: 2021/12/12
- **Media**: Ethernet
still show port 8/1/c7, DDM should be known by now

---

**Transceiver Digital Diagnostic Monitoring (DDM)**

<table>
<thead>
<tr>
<th>Value</th>
<th>High Alarm</th>
<th>High Warn</th>
<th>Low Warn</th>
<th>Low Alarm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature (C)</strong></td>
<td>+48.0</td>
<td>+80.0</td>
<td>+75.0</td>
<td>+15.0</td>
</tr>
<tr>
<td>Supply Voltage (V)</td>
<td>3.26</td>
<td>3.46</td>
<td>3.43</td>
<td>3.17</td>
</tr>
</tbody>
</table>

---

**Transceiver Lane Digital Diagnostic Monitoring (DDM)**

<table>
<thead>
<tr>
<th>Lane Tx Output Power (dBm)</th>
<th>High Alarm</th>
<th>High Warn</th>
<th>Low Warn</th>
<th>Low Alarm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>-2.00</td>
<td>-13.00</td>
<td>-14.00</td>
<td></td>
</tr>
<tr>
<td>Lane Rx Optical Pwr (avg dBm)</td>
<td>2.00</td>
<td>0.00</td>
<td>-21.02</td>
<td>-23.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lane ID</th>
<th>Temp (C)/Alm</th>
<th>Tx Bias (mA)/Alm</th>
<th>Tx Pwr (dBm)/Alm</th>
<th>Rx Pwr (dBm)/Alm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-8.20</td>
<td>0.01/H-W</td>
</tr>
</tbody>
</table>

---
still show port 8/1/c7, DDM should be known by now

---

**Transceiver Digital Diagnostic Monitoring**

<table>
<thead>
<tr>
<th>Value</th>
<th>High Alarm</th>
<th>High Warn</th>
<th>Low Warn</th>
<th>Low Alarm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>48.0</td>
<td>+80.0</td>
<td>+75.0</td>
<td>+15.0</td>
</tr>
<tr>
<td>Supply Voltage (V)</td>
<td>3.26</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Transceiver Lane Digital Diagnostic Monitoring**

| Lane Tx Output Power (dBm) | 0.00 | -2.00 | -13.00 | -14.00 |
| Lane Rx Optical Pwr (avg dBm)| 2.00 | 0.00  | -21.02 | -23.01 |

---

<table>
<thead>
<tr>
<th>Lane ID</th>
<th>Temp (°C)</th>
<th>Alm</th>
<th>Tx Bias (mA)</th>
<th>Alm</th>
<th>Tx Pwr (dBm)</th>
<th>Alm</th>
<th>Rx Pwr (dBm)</th>
<th>Alm</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>-8.20</td>
<td></td>
<td>-1.01</td>
<td>H</td>
<td>-8.01</td>
<td>H-W</td>
</tr>
</tbody>
</table>

---

Coherent optical transceivers

*heat* 16,999 W

*power* 17 W

*light* 0.001 W
still show port 8/1/c7, now it becomes tricky

---

### Coherent Optical Module

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cfg Tx Target Power</td>
<td>1.00 dBm</td>
</tr>
<tr>
<td>Cfg Rx LOS Thresh</td>
<td>-23.00 dBm</td>
</tr>
<tr>
<td>Present Rx Channel</td>
<td>23</td>
</tr>
<tr>
<td>Cfg Rx Channel</td>
<td>23</td>
</tr>
<tr>
<td>Control Mode</td>
<td>automatic</td>
</tr>
<tr>
<td>Sweep Start Disp</td>
<td>-25500 ps/nm</td>
</tr>
<tr>
<td>Sweep End Disp</td>
<td>2000 ps/nm</td>
</tr>
<tr>
<td>Cfg Dispersion</td>
<td>0 ps/nm</td>
</tr>
<tr>
<td>Rx LOS Reaction</td>
<td>squelch</td>
</tr>
<tr>
<td>Cfg Rx Power Min</td>
<td>-22.90 dBm</td>
</tr>
<tr>
<td>Cfg Tx Power Max</td>
<td>4.00 dBm</td>
</tr>
<tr>
<td>Cfg Alarms</td>
<td>modflt mod netrx nettx hosttx</td>
</tr>
<tr>
<td>Alarm Status</td>
<td></td>
</tr>
<tr>
<td>Defect Points</td>
<td></td>
</tr>
<tr>
<td>Rx Q Margin</td>
<td>2.4 dB</td>
</tr>
<tr>
<td>Chromatic Disp</td>
<td>220 ps/nm</td>
</tr>
<tr>
<td>SNR/OSNR X Polar</td>
<td>17.4 dB / 34.4 dB</td>
</tr>
<tr>
<td>Diff Group Delay</td>
<td>2 ps</td>
</tr>
<tr>
<td>SNR/OSNR Y Polar</td>
<td>17.4 dB / 34.4 dB</td>
</tr>
<tr>
<td>Pre-FEC BER</td>
<td>1.213E-03</td>
</tr>
<tr>
<td>Module State</td>
<td>ready</td>
</tr>
<tr>
<td>Tx Turn-Up States</td>
<td>init laserTurnUp laserReadyOff laserReady modulatorConverge outputPowerAdjust</td>
</tr>
<tr>
<td>Rx Turn-Up States</td>
<td>init laserReady waitForInput adcSignal opticalLock demodLock</td>
</tr>
</tbody>
</table>

---
still show port 8/1/c7, the receiver requires its own laser

required to establish the link, no sweeping
still show port 8/1/c7, back in the past with 10G and CWDM this was a major issue ...

---

Coherent Optical Module
---

Cfg Tx Target Power: 1.00 dBm
Cfg Rx LOS Thresh : -23.00 dBm

Disp Control Mode : automatic

Sweep Start Disp: -25500 ps/nm
Sweep End Disp: 2000 ps/nm

If Disp Control Mode is manual:
Configure a target dispersion, where the switch may decide whether to raise warnings or not.

Sweep: With **start** and **end** you indicate a range of allowed dispersion that can be handled by a compensator (DSP in this case)
still show port 8/1/c7, don't be to late

...
still show port 8/1/c7, almost done

OSNR: check datasheet, depends on application mode

Q Margin (Q Factor): gap between the current pre-FEC BER value and error-free threshold in dB

Rx Q Margin : 2.4 dB
OSNR X Polar: 34.4 dB
OSNR Y Polar: 34.4 dB

Pre-FEC BER: 1.213E-03

---

Coherent Optical Module

Cfg Tx Target Power: 1.00 dBm  Present Rx Channel : 23
Cfg Rx LOS Thresh : -23.00 dBm  Cfg Rx Channel : 23

Disp Control Mode : automatic  Sweep Start: -25500 ps/nm
Cfg Dispersion : 0 ps/nm  Sweep End: 2000 ps/nm
CPR Window Size : 32 symbols  Compatibility : openZrpOfecl
Rx LOS Reaction : squelch

Cpr Power Min : -22.90 dBm  Cfg Tx Power Max : 4.00 dBm
Cfg Alarms : modflt mod netrx nettx hosttx
Alarm Status :
Defect Points :

Module State : ready
Tx Turn-Up States : init laserTurnUp laserReadyOff laserReady
modulatorConverge outputPowerAdjust
Rx Turn-Up States : init laserReady waitForInput adcSignal opticalLock
demodLock
still show port 8/1/c7, !?!

---

Coherent Optical Module

Cfg Tx Target Power: 1.00 dBm
Cfg Rx LOS Thresh : -23.00 dBm
Disp Control Mode : automatic

Disp Start Disp : -25500 ps/nm
Disp End Disp : 2000 ps/nm

Comp Window Size : 32 symbols
Rx LOS Reaction : squelch

Comp: openZrpOfec1

Cfg Tx Power Min : -22.90 dBm
Cfg Tx Power Max : 4.00 dBm

---

Compatibility / Application Mode

<table>
<thead>
<tr>
<th>Application Mode</th>
<th>MSA format</th>
<th>Nokia Compatibility</th>
<th>Host format</th>
<th>Nokia Config</th>
<th>Electrical interface</th>
<th>FEC</th>
<th>Modulation</th>
<th>Line Symbol</th>
<th>Baud Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OIF 400ZR, amplified</td>
<td>oif-400g-zr</td>
<td>400GBASE-R</td>
<td>c1-400g</td>
<td>1x 400GAUI-8 (8x 50G)</td>
<td>CFEC</td>
<td>DP-16QAM</td>
<td>59.8Gbd</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>OIF 400ZR, unamplified</td>
<td>400GBASE-R</td>
<td>400GBASE-R</td>
<td>1x 400GAUI-8 (8x 50G)</td>
<td>CFEC</td>
<td>DP-16QAM</td>
<td>59.8Gbd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3*</td>
<td>OpenZR+ MSA</td>
<td>openZrpOfec1</td>
<td>400GBASE-R</td>
<td>c1-400g</td>
<td>1x 400GAUI-8 (8x 50G)</td>
<td>oFEC</td>
<td>DP-16QAM</td>
<td>60.1Gbd</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>OpenZR+ MSA</td>
<td>2x 200GBASE-R</td>
<td>2x 200GBASE-R</td>
<td>c4-100g</td>
<td>4x 100GAUI-2 (4x 50G)</td>
<td>oFEC</td>
<td>DP-16QAM</td>
<td>60.1Gbd</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>OpenZR+ MSA</td>
<td>openZrpOfec1</td>
<td>4x 100GBASE-R</td>
<td>c4-100g</td>
<td>4x 100GAUI-2 (4x 50G)</td>
<td>oFEC</td>
<td>DP-16QAM</td>
<td>60.1Gbd</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>OpenZR+ MSA, Enhanced</td>
<td>openZrpOfec2</td>
<td>400GBASE-R</td>
<td>c1-400g</td>
<td>1x 400GAUI-8 (8x 50G)</td>
<td>oFEC</td>
<td>DP-16QAM</td>
<td>60.1Gbd</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>OpenZR+ MSA, Enhanced</td>
<td>openZrpOfec2</td>
<td>2x 200GBASE-R</td>
<td>c4-100g</td>
<td>2x 200GAUI-4 (4x 50G)</td>
<td>oFEC</td>
<td>DP-16QAM</td>
<td>60.1Gbd</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>OpenZR+ MSA, Enhanced</td>
<td>openZrpOfec2</td>
<td>4x 100GBASE-R</td>
<td>c2-100g-aui2</td>
<td>2x 100GAUI-2 (2x 50G)</td>
<td>oFEC</td>
<td>DP-16QAM</td>
<td>60.1Gbd</td>
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<tr>
<td>9</td>
<td>OpenZR+ MSA</td>
<td>openZrpOfec1</td>
<td>2x 100GBASE-R</td>
<td>c2-100g-aui2</td>
<td>2x 100GAUI-2 (2x 50G)</td>
<td>oFEC</td>
<td>DP-16QAM</td>
<td>60.1Gbd</td>
<td></td>
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<tr>
<td>10</td>
<td>OpenZR+ MSA</td>
<td>openZrpOfec2</td>
<td>1x 100GBASE-R</td>
<td>c1-100g-aui2</td>
<td>1x 100GAUI-2 (2x 50G)</td>
<td>oFEC</td>
<td>DP-16QAM</td>
<td>30.1Gbd</td>
<td></td>
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<tr>
<td>11</td>
<td>OpenZR+ MSA</td>
<td>openZrpOfec1</td>
<td>3x 100GBASE-R</td>
<td>c3-100g</td>
<td>3x 100GAUI-2 (2x 50G)</td>
<td>oFEC</td>
<td>DP-16QAM</td>
<td>60.1Gbd</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>OpenZR+ MSA, Enhanced</td>
<td>openZrpOfec1</td>
<td>3x 100GBASE-R</td>
<td>3x 100GAUI-2 (2x 50G)</td>
<td>oFEC</td>
<td>DP-16QAM</td>
<td>60.1Gbd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>OIF 400ZR, amplified</td>
<td>oif-400g-zr</td>
<td>4x 100GBASE-R</td>
<td>c4-100g</td>
<td>4x 100GAUI-2 (2x 50G)</td>
<td>CFEC</td>
<td>DP-16QAM</td>
<td>59.8Gbd</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>OpenZR+ MSA, Enhanced</td>
<td>openZrpOfec2</td>
<td>2x 100GBASE-R</td>
<td>c2-100g-aui2</td>
<td>2x 100GAUI-2 (2x 50G)</td>
<td>oFEC</td>
<td>DP-16QAM</td>
<td>30.1Gbd</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>OpenZR+ MSA</td>
<td>100GBASE-R</td>
<td>1x CAUI-4 w/o FEC (4x25G)</td>
<td>oFEC</td>
<td>DP-16QAM</td>
<td>30.1Gbd</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
still show port 8/1/c7, !??

...
## OIF 400ZR vs. OpenZR+ MSA optical parameters

<table>
<thead>
<tr>
<th></th>
<th>OIF 400ZR</th>
<th>OpenZR+ MSA 60LA</th>
<th>OpenZR+ MSA 60HA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>max. TX power</strong></td>
<td>-6 dBm</td>
<td>-10 dbm</td>
<td>0 dBm</td>
</tr>
<tr>
<td><strong>min. RX power</strong></td>
<td>-12 dBm</td>
<td>-12 dBm</td>
<td>-12 dBm</td>
</tr>
<tr>
<td><strong>CD Tolerance</strong></td>
<td>2,400 ps/nm</td>
<td>20,000 ps/nm</td>
<td></td>
</tr>
<tr>
<td><strong>PMD Tolerance</strong></td>
<td>10 ps</td>
<td>20 ps</td>
<td></td>
</tr>
<tr>
<td><strong>OSNR Tolerance</strong></td>
<td>26 dB</td>
<td>24 dB</td>
<td></td>
</tr>
</tbody>
</table>
more bandwidth for 800G, 1.6T or 3.2T with coherent

Option 1: IMDD, doubling baudrate
Option 2: coherent TRx, DP-QPSK
Option 3: coherent TRx, DP-16QAM

Baudrate/lane (excl. FEC overhead)

source: [1]
Want to learn for yourself?

Your switch gear + our coherent optics = less hickups, more knowhow
Outlook: OpenXR 16 x 25Gbit/s via DSCM

Point-to-Point

100G/200G/400G P2P

Break-out Mode

4 X 100G LEAFS TO 400G HUB

Flexible Point-to-Multipoint

UP TO 16 LEAFS TO 400G HUB

source: [7]
Outlook: DSCM (Digital SubCarrier Multiplexing)

Break-out Mode

4 X 100G LEAFS TO 400G HUB

source: [7]

(a)

Downlink Spectrum - Hub
Uplink Spectrum - Leaf 1
Uplink Spectrum - Leaf 2

Normalized Power (dB)

Optical Frequency (THz)

source: [8]
References

1. High Speed Transceivers beyond 1.6Tb/s for Data Centre Networks, Osseiur et al. 2023, Ghent University – imec, Belgium
2. Introduction to Applications of XR Optics to Coherent Optical Communication Networks OXR DOCUMENT OXR.APPS-INTRO.01.0; July 2022
4. 400G ZR(+) Real World Examples, Florian Hibler, Arista ; Networks GmbH ; DENOG14 (Nov. 2022)
5. OIF-400ZR-02.0, Implementation Agreement 400ZR, OIForum; November 3rd of 2022
8. SFF-8024, SFF Module Management Reference Code Tables, Rev. 4.10, November 24th of 2022