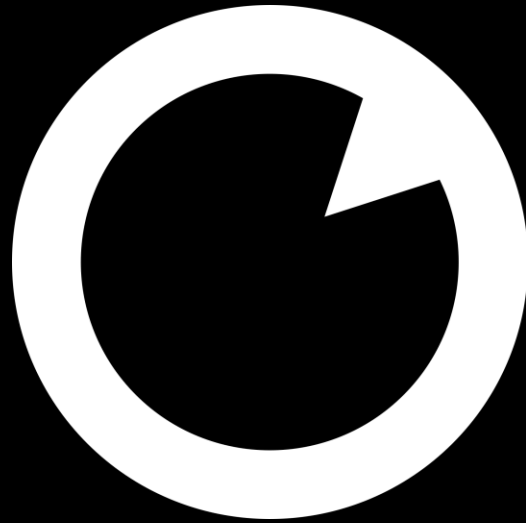


Coherent optical transceivers



current capabilities and
future possibilities

Summary

400G-ZR+

- 400G-ZR+ is a $> 120\text{km}$ long haul solution
 - Low optical output power \rightarrow not compatible with most brownfield long haul line systems
 - Not compatible with every platform due to power and thermal constraints
 - Transceivers vary between 18W and 25W - it is very inconsistent
 - **Using those transceiver in unsupported platforms could irreversibly damage your device!**
- 400G-ZR+ with $> 0\text{dBm}$ Tx power is compatible with most long-haul line systems
 - 400G-ZR+ transceivers with $> 0\text{dBm}$ Tx power not available yet
 - **Even higher power consumption, so always check platform support as this could irreversibly damage your device!**
 - Customer needs to test & validate 3rd party line systems w/ their optical vendors

source: [4]

Summary

400G-ZR+

- 400G-ZR+ is a > 120km long haul solution
 - Low optical output power → not compatible with most brownfield long haul line systems
 - Not compatible with every platform due to power and thermal constraints
 - Transceivers vary between 18W and 25W - it is very inconsistent

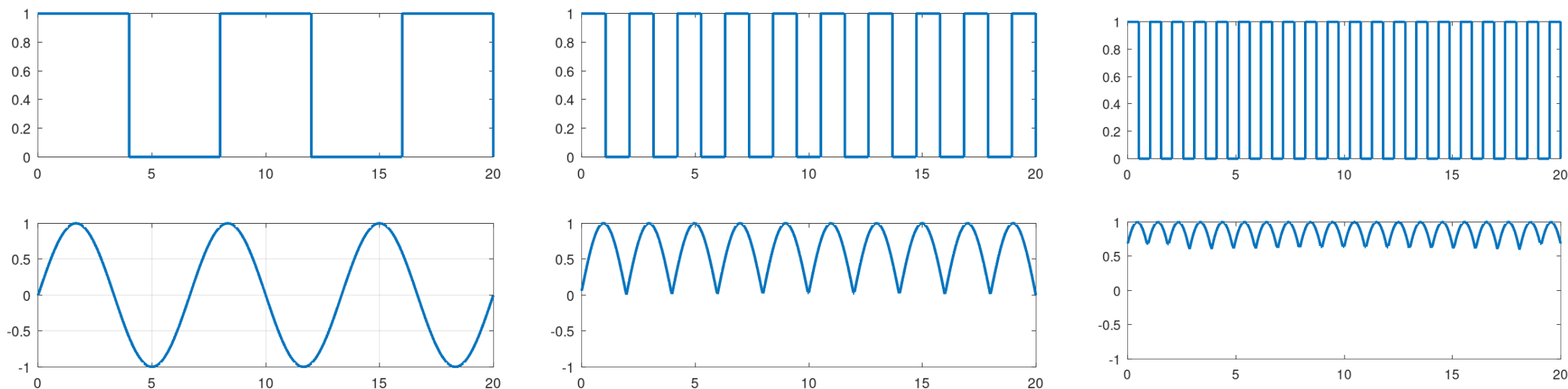
 Using those transceiver in unsupported platforms could irreversibly damage your device!

- 400G-ZR+ with > 0dBm Tx power is compatible with most long-haul line systems
 - 400G-ZR+ transceivers with > 0dBm Tx power not available yet
 - Even higher power consumption, so always check platform support as this could irreversibly damage your device!
 - Customer needs to test & validate 3rd party line systems w/ their optical vendors

source: [4]

Direct Detection Transceiver limits

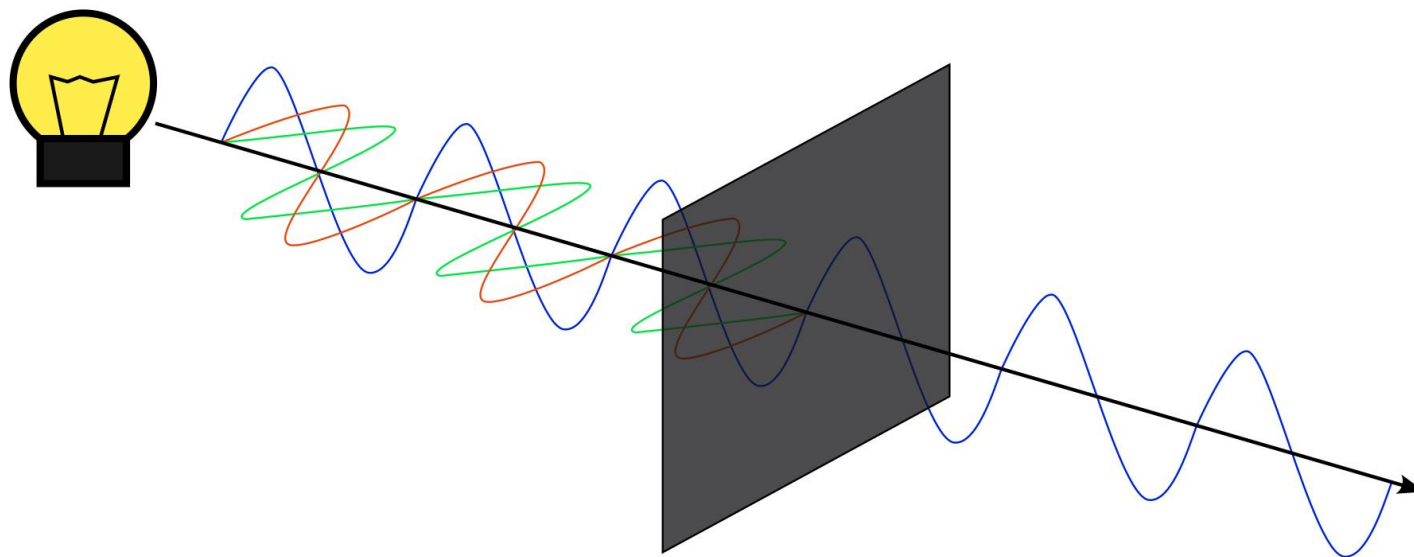
With **higher** frequencies -> harder for Photodiodes to detect



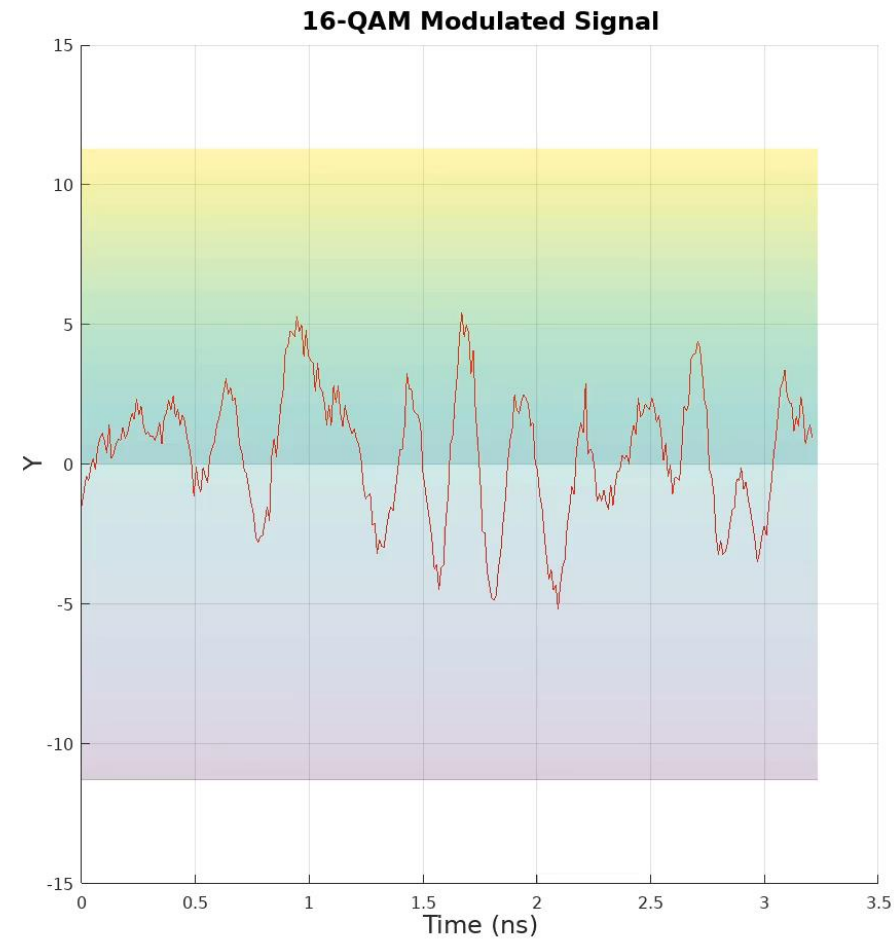
Missed Opportunity: **Light** has more **Properties**

Main Properties of Photonic Waves

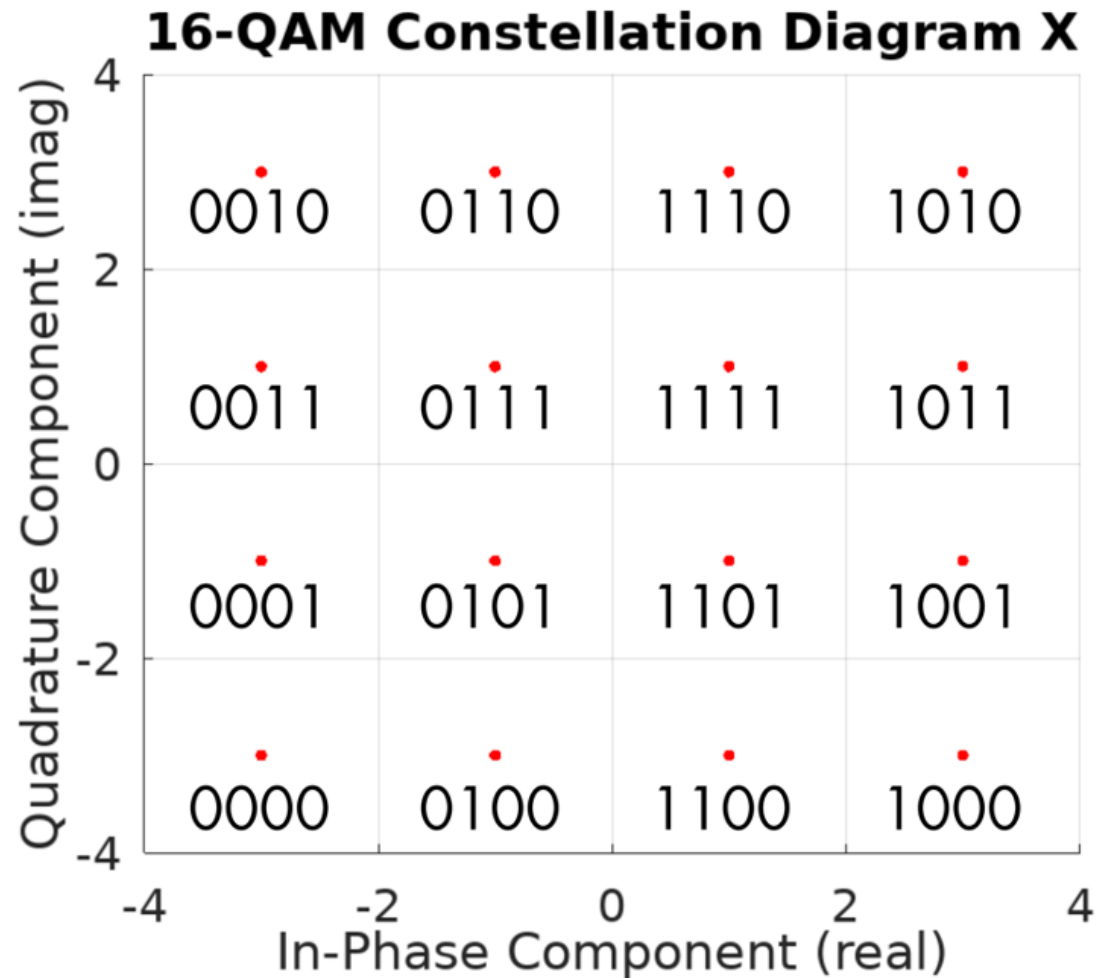
- Besides **Amplitude**, also **Phase** and **Polarisation**
- More properties per Carrier = Higher Bandwidth



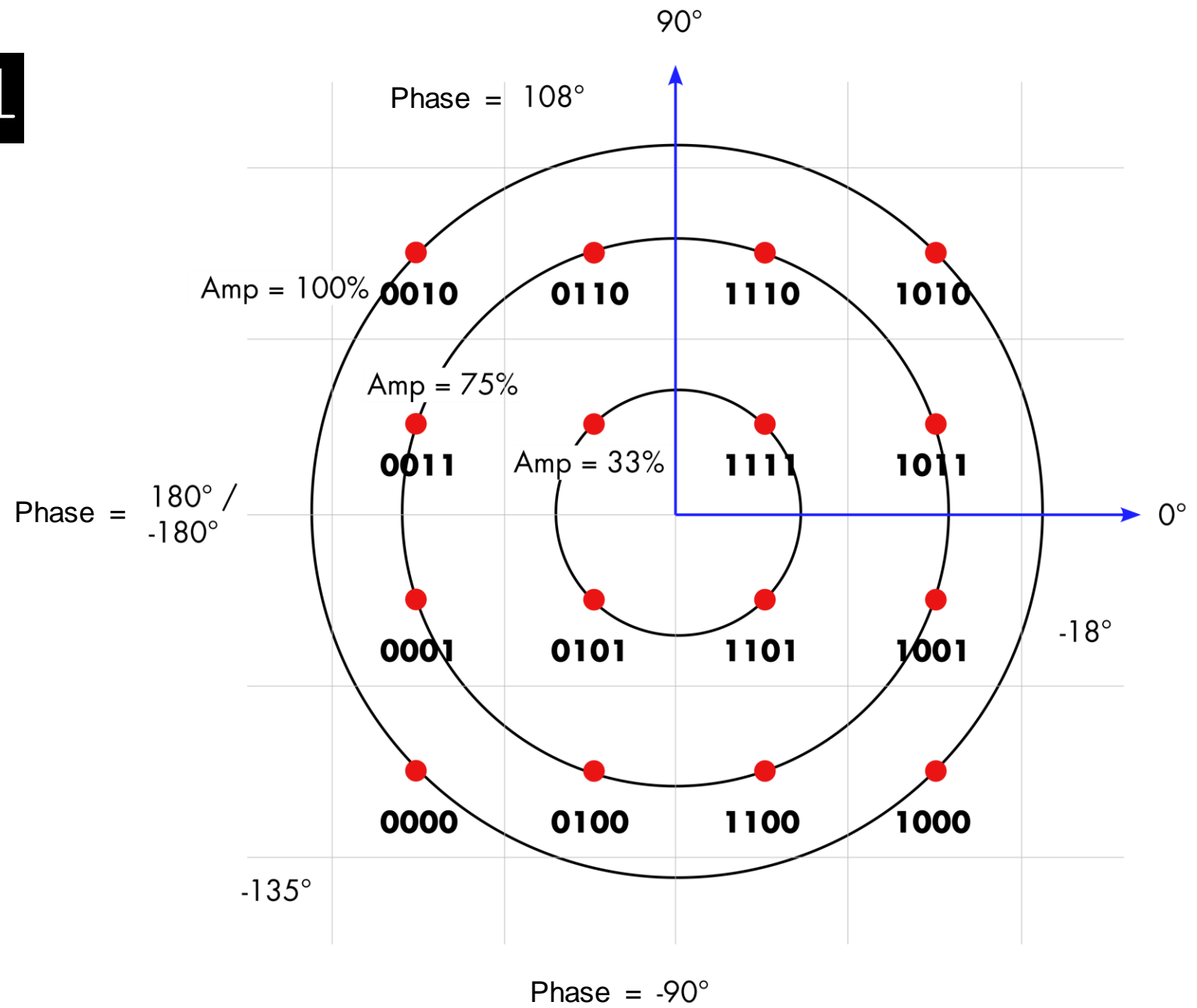
Polarisation Signal on X and Y Plane



Bit Sequence in 16QAM



1111 0101 0011

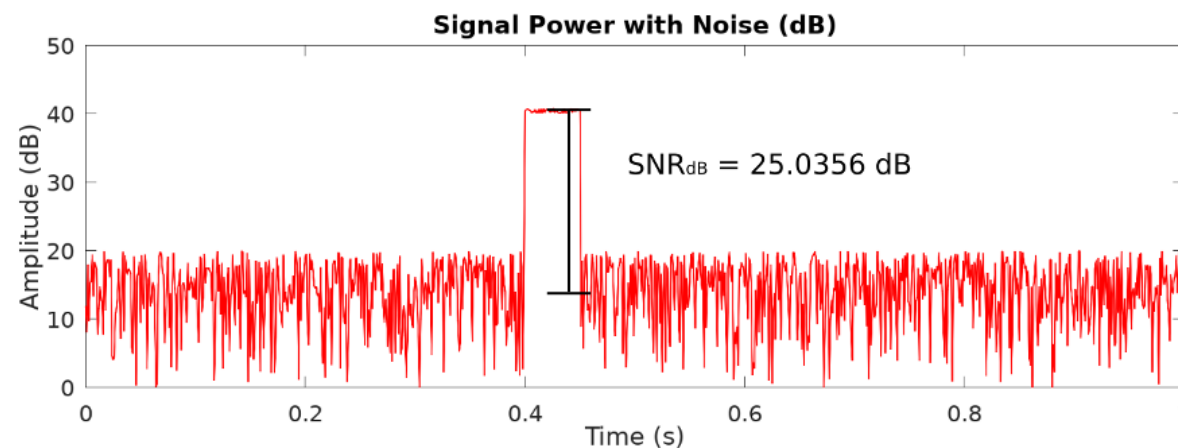


Bit Error Rate:

$$\text{BER} = \frac{\# \text{ erroneous Bits}}{\# \text{ xferred Bits}}$$

Measuring Signal Quality

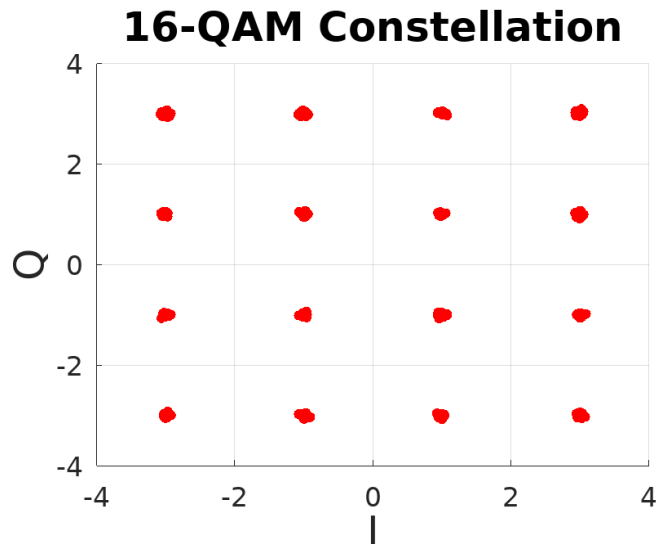
- **SNR** = Signal-to-Noise-Ratio
- Convenience of using decibels for **small** and **large** values
- (e)SNR vs OSNR :
electrical vs optical



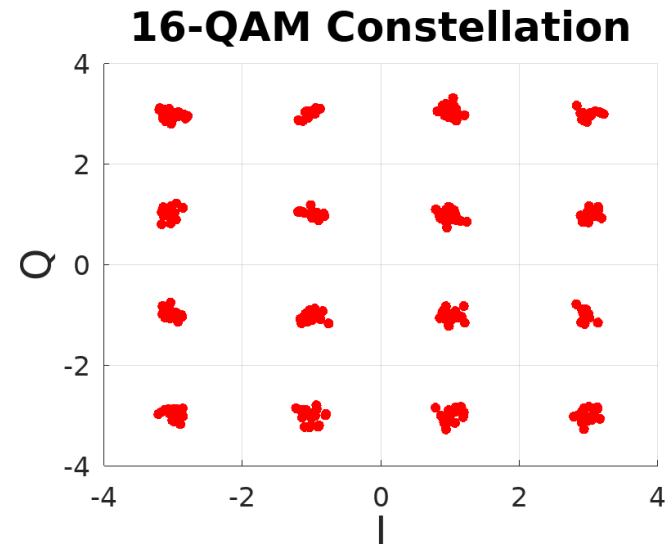
Bit Error Ratio or Bit Error Rate:

$$\text{BER} = \frac{\# \text{ erroneous Bits}}{\# \text{ xferred Bits}}$$

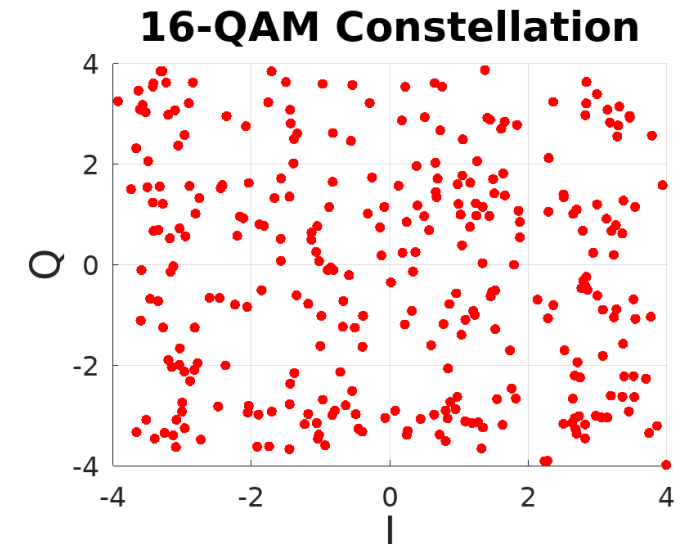
Phase and Amplitude Errors



SNR = 30 dB



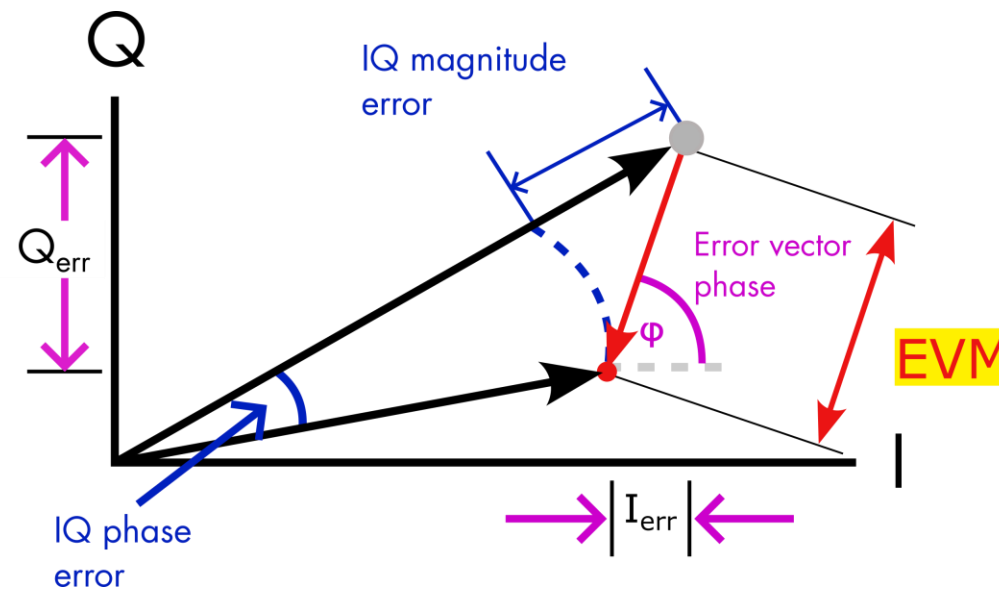
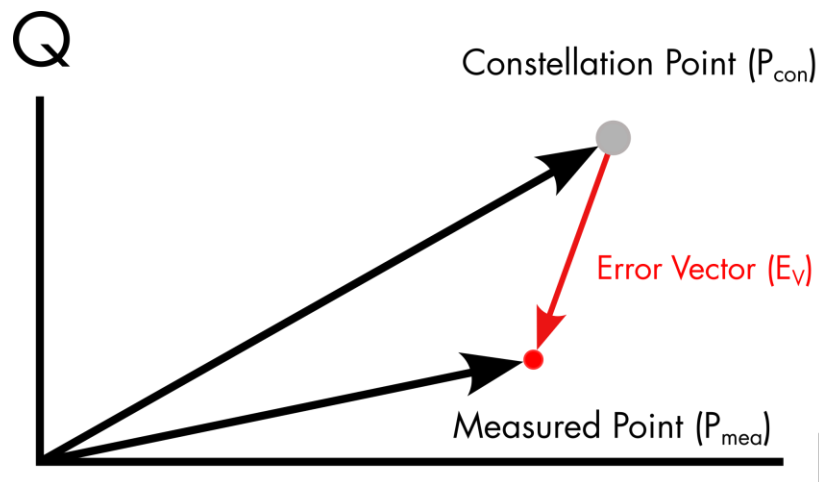
SNR = 20 dB



SNR = 5 dB

NOTE: Polarisation Error not considered

Error Vector Magnitude



$$EVM = |\vec{E}_V| = |\vec{P}_{con} - \vec{P}_{mea}|$$

P_{con} → Constellation Point

P_{mea} → Measured Point

E_V → Error Vector

NOKIA SR-OS and 400G ZR Transceiver



+



=

terrific
coherent
workshop

source: Daniel Melzer; DE-CIX

source: <https://www.flexoptix.net/en/d-co164hg-2-yt.html>

config with the CLI

```
Nokia 7950 XRS# show port 8/1/c7

=====
QSFP-DD Connector
=====
Description          : -
Interface            : 8/1/c7
FP Number            : 2
MAC Chip Number      : 3
...
Breakout             : c1-400g
RS-FEC Config Mode  : None

Transceiver Data

Transceiver Status  : operational
Transceiver Type    : QSFP-DD
Model Number        : 3HE16564AARA01 NOK INUIAPHHAA
TX Laser Wavelength: 1558.983 nm
DCO                  : Enabled
Present Channel     : 23
Configured Chann*  : 23

Laser Tunability    : flex-tunable
Config Freq (MHz)   : 0
Oper Freq (MHz)     : 192300000
Fine Tune Range     : 6000 MHz
Supported Grids     : 100GHz 75GHz 50GHz 25GHz 12.5GHz 6.25GHz
Diag Capable        : yes
Number of Lanes     : 1
Connector Code      : LC
Manufacture date    : 2021/12/12
Vendor OUI          : 20:20:20
Media                : Ethernet
...
Optical Compliance : 400G-ZR-Amp 400G-ZR-Unamp
Link Length support: Unknown
...
```

analysis with the CLI

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

```
...
```

```
=====  
Transceiver Digital Diagnostic Monitoring (DDM)  
=====
```

| | Value | High Alarm | High Warn | Low Warn | Low Alarm |
|--------------------|-------|------------|-----------|----------|-----------|
| Temperature (C) | +48.0 | +80.0 | +75.0 | +15.0 | -5.0 |
| Supply Voltage (V) | 3.26 | 3.46 | 3.43 | 3.17 | 3.13 |

```
=====  
Transceiver Lane Digital Diagnostic Monitoring (DDM)  
=====
```

| | High Alarm | High Warn | Low Warn | Low Alarm |
|-------------------------------|------------|-----------|----------|-----------|
| 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 |

```
-----  
Lane ID Temp(C)/Alm      Tx Bias(mA)/Alm      Tx Pwr(dBm)/Alm      Rx Pwr(dBm)/Alm  
-----
```

| | | | | |
|---|---|---|-------|----------|
| 1 | - | - | -8.20 | 0.01/H-W |
|---|---|---|-------|----------|

```
=====  
...
```

the interesting part

```
still show port 8/1/c7, now it becomes tricky

...

=====
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 Disp  : -25500 ps/nm
Cfg Dispersion      :      0 ps/nm       Sweep End Disp    :  2000 ps/nm
CPR Window Size     : 32 symbols         Rx LOS Reaction   : squelch
Compatibility       : openZrpOfec1
Cfg Tx Power Min    : -22.90 dBm        Cfg Tx Power Max  :   4.00 dBm

Cfg Alarms          : modflt mod netrx nettx hosttx
Alarm Status       :
Defect Points      :

Rx Q Margin        :   2.4 dB            Chromatic Disp    :   220 ps/nm
SNR/OSNR X Polar   :  17.4 dB / 34.4 dB  Diff Group Delay  :    2 ps
SNR/OSNR Y Polar   :  17.4 dB / 34.4 dB  Pre-FEC BER      : 1.213E-03

Module State       : ready
Tx Turn-Up States  : init laserTurnUp laserReadyOff laserReady
                   : modulatorConverge outputPowerAdjust
Rx Turn-Up States  : init laserReady waitForInput adcSignal opticalLock
                   : demodLock

=====
```

RX Channel

```
still show port 8/1/c7, the receiver requires its own laser
...
=====
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
```

required to establish the link, no sweeping

```
Rx Q Margin      : 2.4 dB           Chromatic Disp   : 220 ps/nm
SNR/OSNR X Polar : 17.4 dB / 34.4 dB  Diff Group Delay : 2 ps
SNR/OSNR Y Polar : 17.4 dB / 34.4 dB  Pre-FEC BER     : 1.213E-03

Module State     : ready
Tx Turn-Up States : init laserTurnUp laserReadyOff laserReady
                  modulatorConverge outputPowerAdjust
Rx Turn-Up States : init laserReady waitForInput adcSignal opticalLock
                  demodLock
=====
```


Chromatic Dispersion (CD)

```
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 Present Rx Channel : 23  
Cfg Rx LOS Thresh : -23.00 dBm Cfg Rx Channel : 23
```

```
Disp Control Mode : automatic Sweep Start Disp : -25500 ps/nm  
Cfg Dispersion : 0 ps/nm Sweep End Disp : 2000 ps/nm  
CDP Window Size : 22 symbols Rx LOS Reaction : squelch
```

```
Cfg Tx Power Max : 4.00 dBm
```

```
hosttx
```

```
Chromatic Disp : 220 ps/nm  
Diff Group Delay : 2 ps  
Pre-FEC BER : 1.213E-03
```

```
ReadyOff laserReady  
utPowerAdjust  
rInput adcSignal opticalLock  
=====
```

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)

Difference in propagation time for X and Y polarisation

```
still show port 8/1/c7, don't be to late

...

=====
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 Disp  : -25500 ps/nm
Cfg Dispersion    :      0 ps/nm        Sweep End Disp   :   2000 ps/nm
Rx LOS Reaction   : squelch

Cfg Tx Power Max   :      4.00 dBm

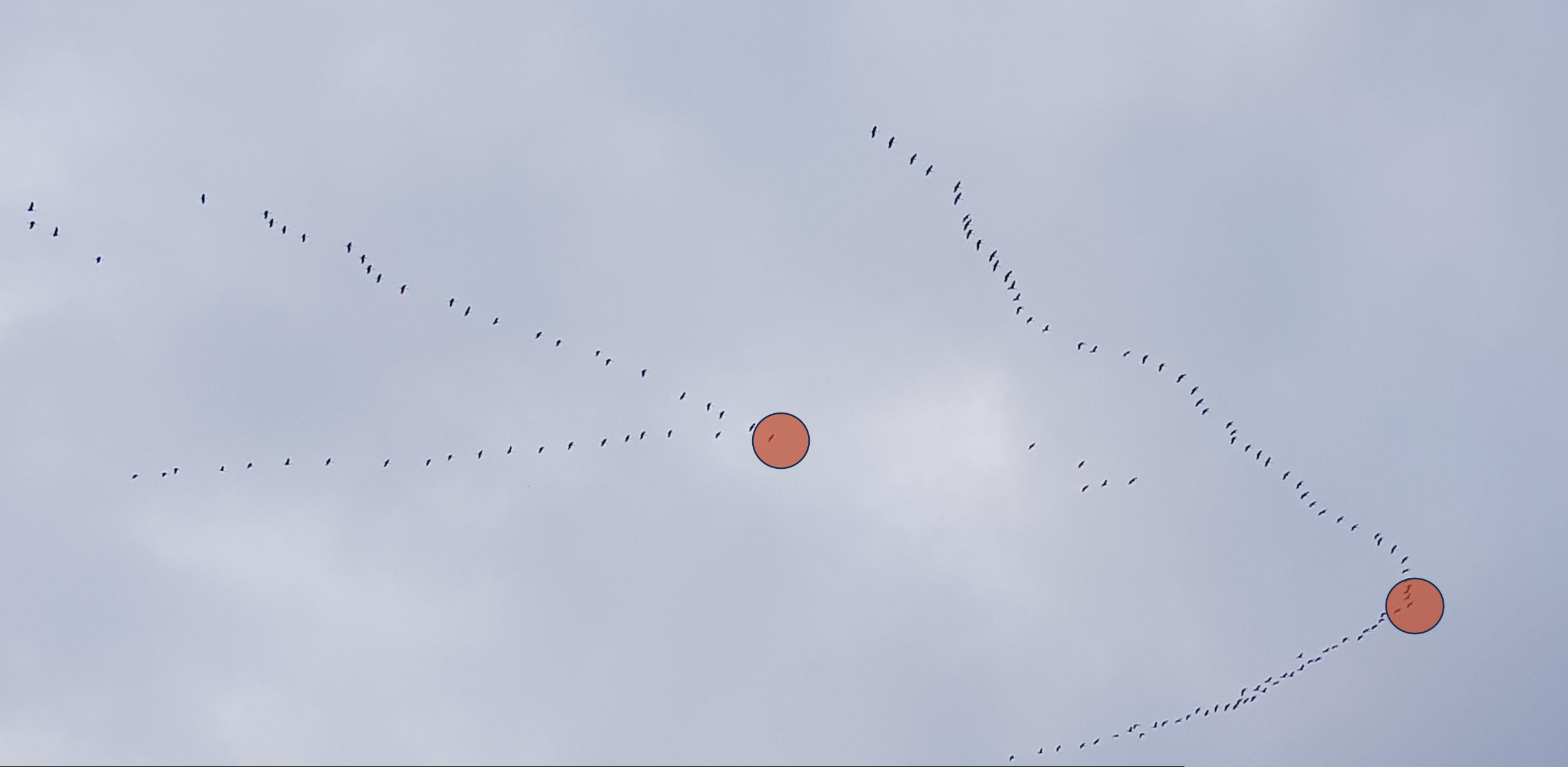
hosttx

Chromatic Disp    :      220 ps/nm
Diff Group Delay  :      2 ps
Pre-FEC BER       : 1.213E-03

ReadyOff laserReady
utPowerAdjust
rInput adcSignal opticalLock

=====
```





who is the pilot this morning ?

Carrier Phase Recovery (CPR)

```
still show port 8/1/c7, we got 4 pilots
```

```
...
=====
Coherent Optical Module
=====
Cfg Tx Target Power:  1.00 dBm
Cfg Rx LOS Thresh   : -23.00 dBm

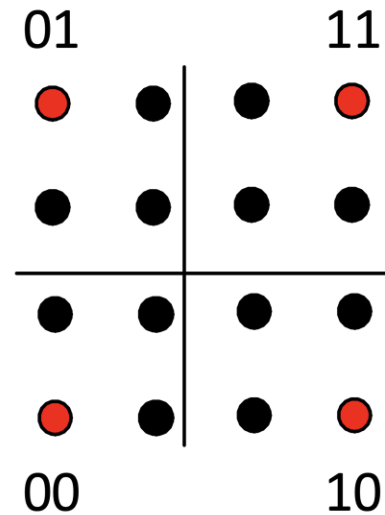
Disp Control Mode   : automatic
Cfg Dispersion      :      0 ps/nm
CPR Window Size     : 32 symbols
Compatibility       : openZrpOfec1
Cfg Tx Power Min    : -22.90 dBm

Cfg Alarms          : modflt mod netrx nettx h
Alarm Status       :
Defect Points      :

Rx Q Margin        :  2.4 dB
SNR/OSNR X Polar   : 17.4 dB / 34.4 dB
SNR/OSNR Y Polar   : 17.4 dB / 34.4 dB

Module State       : ready
Tx Turn-Up States  : init laserTurnUp laserRea
                   modulatorConverge outputI
Rx Turn-Up States  : init laserReady waitForI
                   demodLock
=====
```

Pilot Sequence: Signal for verification and recovery (rotated 16QAM f.e.) with using QPSK (Quadrature Phase Shift Keying), the red dots.



Signal-to-Noise Ratio (SNR)

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

```
...
```

```
-----  
Coherent Optical Module  
-----
```

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

```
Disp Control Mode : automatic  
Cfg Dispersion : 0 ps/nm  
CPR Window Size : 32 symbols  
Compatibility : openZrpOfec1  
Cfg Tx Power Min : -22.90 dBm
```

```
Cfg Alarms : modflt mod netrx nettx h  
Alarm Status :  
Defect Points :
```

```
Rx Q Margin : 2.4 dB  
SNR/OSNR X Polar : 17.4 dB / 34.4 dB  
SNR/OSNR Y Polar : 17.4 dB / 34.4 dB
```

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

```
Pre-FEC BER : 1.213E-03
```

```
Module State : ready  
Tx Turn-Up States : init laserTurnUp laserReadyOff laserReady  
modulatorConverge outputPowerAdjust  
Rx Turn-Up States : init laserReady waitForInput adcSignal opticalLock  
demodLock
```

```
-----
```

Compatibility / Application Mode

```
still show port 8/1/c7, !??
```

```
...
```

```
=====
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 Disp : -25500 ps/nm
Cfg Dispersion : 0 ps/nm Sweep End Disp : 2000 ps/nm
CPR Window Size : 32 symbols Rx LOS Reaction : squelch
```

```
Compatibility : openZrpOfec1
```

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

| Application Mode | MSA format | Nokia Compatibility | Host format | Nokia Config | Electrical interface | FEC | Modulation | Line Symbol Baud Rate |
|------------------|------------------------|---------------------|---------------|--------------|---------------------------|------|------------|-----------------------|
| 1 | OIF 400ZR, amplified | oif-400g-zr | 400GBASE-R | c1-400g | 1x 400GAUI-8 (8x 50G) | CFEC | DP-16QAM | 59.8GBd |
| 2 | OIF 400ZR, unamplified | | 400GBASE-R | | 1x 400GAUI-8 (8x 50G) | CFEC | DP-16QAM | 59.8GBd |
| 3 | OpenZR+ MSA | openZrpOfec1 | 400GBASE-R | c1-400g | 1x 400GAUI-8 (8x 50G) | oFEC | DP-16QAM | 60.1GBd |
| 4 | OpenZR+ MSA | | 2x 200GBASE-R | | 2x 200GAUI-4 (4x 50G) | oFEC | DP-16QAM | 60.1GBd |
| 5 | OpenZR+ MSA | openZrpOfec1 | 4x 100GBASE-R | c4-100g | 4x 100GAUI-2 (2x 50G) | oFEC | DP-16QAM | 60.1GBd |
| 6 | OpenZR+ MSA, Enhanced | openZrpOfec2 | 400GBASE-R | c1-400g | 1x 400GAUI-8 (8x 50G) | oFEC | DP-16QAM | 60.1GBd |
| 7 | OpenZR+ MSA, Enhanced | | 2x 200GBASE-R | | 2x 200GAUI-4 (4x 50G) | oFEC | DP-16QAM | 60.1GBd |
| 8 | OpenZR+ MSA, Enhanced | openZrpOfec2 | 4x 100GBASE-R | c4-100g | 4x 100GAUI-2 (2x 50G) | oFEC | DP-16QAM | 60.1GBd |
| 9 | OpenZR+ MSA | openZrpOfec1 | 2x 100GBASE-R | c2-100g-ai2 | 2x 100GAUI-2 (2x 50G) | oFEC | DP-QPSK | 60.1GBd |
| 10 | OpenZR+ MSA | openZrpOfec2 | 1x 100GBASE-R | c1-100g-ai2 | 1x 100GAUI-2 (2x 50G) | oFEC | DP-QPSK | 30.1GBd |
| 11 | OpenZR+ MSA | openZrpOfec1 | 3x 100GBASE-R | c3-100g | 3x 100GAUI-2 (2x 50G) | oFEC | DP-8QAM | 60.1GBd |
| 12 | OpenZR+ MSA, Enhanced | | 3x 100GBASE-R | | 3x 100GAUI-2 (2x 50G) | oFEC | DP-8QAM | 60.1GBd |
| 13 | OIF 400ZR, amplified | oif-400g-zr | 4x 100GBASE-R | c4-100g | 4x 100GAUI-2 (2x 50G) | CFEC | DP-16QAM | 59.8GBd |
| 14 | OpenZR+ MSA, Enhanced | openZrpOfec2 | 2x 100GBASE-R | c2-100g-ai2 | 2x 100GAUI-2 (2x50G) | oFEC | DP-16QAM | 30.1GBd |
| 15 | OpenZR+ MSA | | 100GBASE-R | | 1x CAUI-4 w/o FEC (4x25G) | oFEC | DP-QPSK | 30.1GBd |

Compatibility / Application Mode

```

still show port 8/1/c7, !??

...

=====
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
Cfg Dispersion     : 0 ps/nm
CPR Window Size    : 32 symbols
Compatibility      : openZrpOfec1
Cfg Tx Power Min   : -22.90 dBm
  
```

```

Nokia 7950 XRS# show port 8/1/c7

=====
QSFP-DD Connector
=====
Description       : -
Interface         : 8/1/c7
FP Number         : 2
...
Breakout          : c1-400g
RS-FEC Config Mode : None

Transceiver Data
...
Laser Tunability  : flex-tunable
Config Freq (MHz) : 0
Oper Freq (MHz)   : 192300000
Fine Tune Range   : 6000 MHz
Supported Grids   : 100GHz 75GHz 50GHz 25GHz
...
Optical Compliance : 400G-ZR-Amp 400G-ZR-Unamp
Link Length support: Unknown
  
```

| Application Mode | MSA format | Nokia Compatibility |
|------------------|------------------------|---------------------|
| 1 | OIF 400ZR, amplified | oif-400g-zr |
| 2 | OIF 400ZR, unamplified | |
| 3 | OpenZR+ MSA | openZrpOfec1 |
| 4 | OpenZR+ MSA | |
| 5 | OpenZR+ MSA | openZrpOfec1 |
| 6 | OpenZR+ MSA, Enhanced | openZrpOfec2 |
| 7 | OpenZR+ MSA, Enhanced | |
| 8 | OpenZR+ MSA, Enhanced | openZrpOfec2 |
| 9 | OpenZR+ MSA | openZrpOfec1 |
| 10 | OpenZR+ MSA | openZrpOfec1 |
| 11 | OpenZR+ MSA | openZrpOfec1 |
| 12 | OpenZR+ MSA, Enhanced | |
| 13 | OIF 400ZR, amplified | oif-400g-zr |
| 14 | OpenZR+ MSA, Enhanced | openZrpOfec2 |
| 15 | OpenZR+ MSA | |

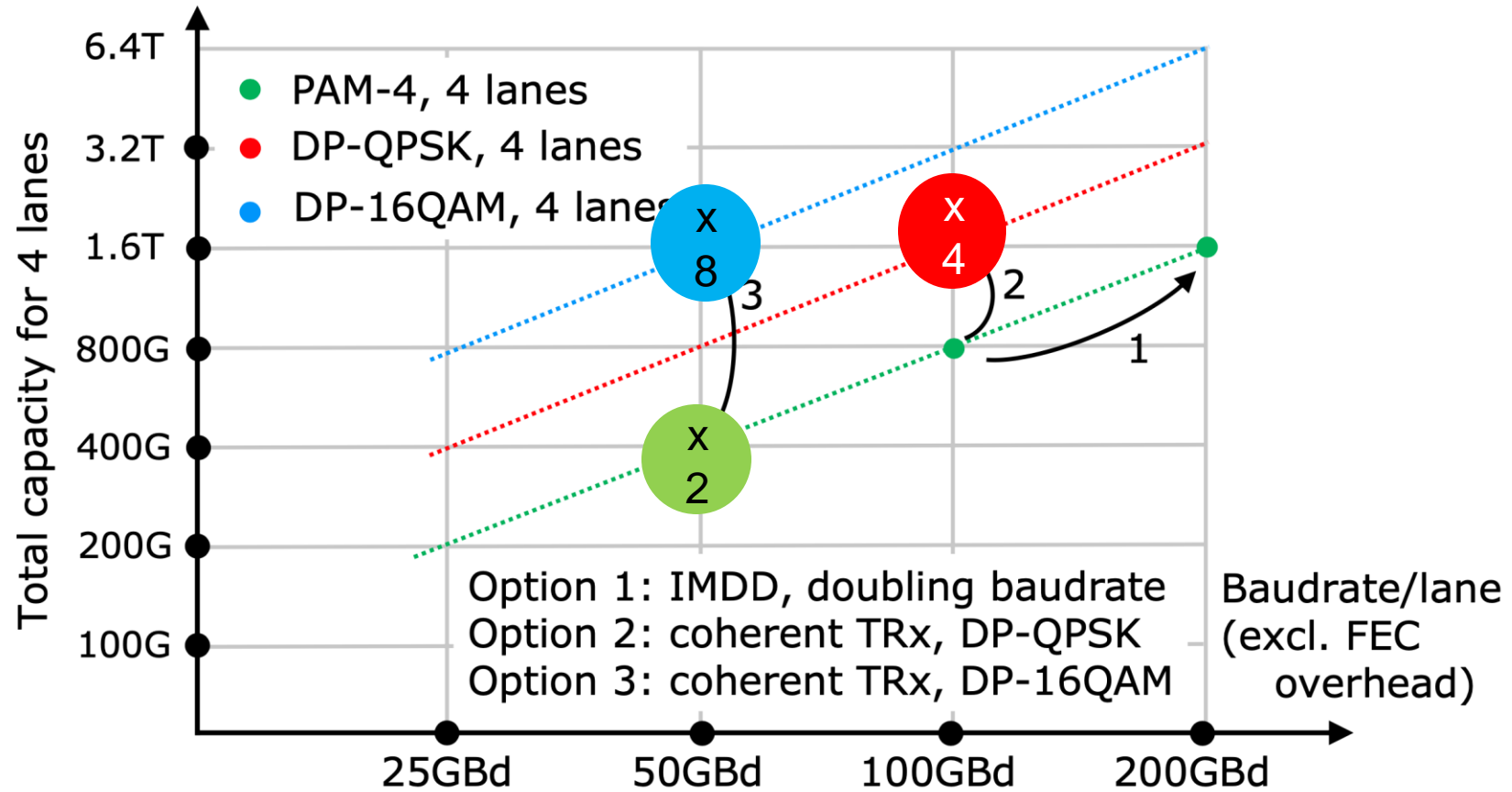
| FEC | Modulation | Line Symbol Baud Rate |
|------|------------|-----------------------|
| CFEC | DP-16QAM | 59.8GBd |
| CFEC | DP-16QAM | 59.8GBd |
| oFEC | DP-16QAM | 60.1GBd |
| oFEC | DP-16QAM | 60.1GBd |
| oFEC | DP-16QAM | 60.1GBd |
| oFEC | DP-16QAM | 60.1GBd |
| oFEC | DP-16QAM | 60.1GBd |
| oFEC | DP-QPSK | 60.1GBd |
| oFEC | DP-QPSK | 30.1GBd |
| oFEC | DP-8QAM | 60.1GBd |
| oFEC | DP-8QAM | 60.1GBd |
| CFEC | DP-16QAM | 59.8GBd |
| oFEC | DP-16QAM | 30.1GBd |
| oFEC | DP-QPSK | 30.1GBd |

| | | |
|---------------|--------------|---------------------------|
| 2x 100GBASE-R | c2-100g-aii2 | 2x 100GAUI-2 (2x50G) |
| 100GBASE-R | | 1x CAUI-4 w/o FEC (4x25G) |

Table 4-7 SMF media interface IDs

| ID | ID (Hex) | SM Media Interface (Specification Reference) | Application Bit Rate, Gb/s | Lane Count | Lane Signaling Rate, GBd | Modulation | b/UI |
|----|----------|---|----------------------------|------------|--------------------------|------------|------|
| 0 | 0 | Undefined | | | | | |
| | | Ethernet | | | | | |
| 1 | 1 | 10GBASE-LW (Clause 52) | 9.95 | 1 | 9.95328 | NRZ | 1 |
| 2 | 2 | 10GBASE-EW (Clause 52) | 9.95 | 1 | 9.953 | NRZ | 1 |
| 3 | 3 | 10G-ZW | 9.95 | 1 | 9.953 | NRZ | 1 |
| 4 | 4 | 10GBASE-LR (Clause 52) | 10.31 | 1 | 10.3125 | NRZ | 1 |
| 5 | 5 | 40GBASE-LR4 (Clause 151) | 42.31 | 4 | 10.3125 | NRZ | 1 |
| 29 | 1D | 400G-FR4 MSA spec ² /400GBASE-FR4 (Clause 151) | 425.00 | 4 | 53.125 | PAM4 | 2 |
| 67 | 43 | 400GBASE-LR4-6 (Clause 151) | 425.00 | 4 | 53.125 | PAM4 | 2 |
| 30 | 1E | 400G-LR4-10 MSA Spec ² | 425.00 | 4 | 53.125 | PAM4 | 2 |
| 77 | 4D | 400GBASE-ZR (Clause 156) | 478.75 | 1 | 59.84375 | DP-16QAM | 8 |
| 86 | 56 | 800GBASE-DR8 (placeholder) | 850.00 | 8 | 53.125 | PAM4 | 2 |
| 87 | 57 | 800GBASE-DR8-2 (placeholder) | 850.00 | 8 | 53.125 | PAM4 | 2 |

Outlook: more Bandwidth for 800G, 1.6T or even 3.2T



source: [1]

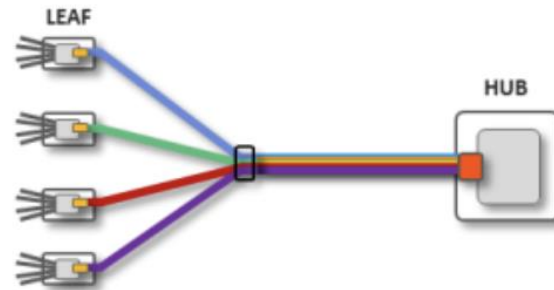
Outlook: OpenXR 16 x 25Gbit/s via DSCM

Point-to-Point



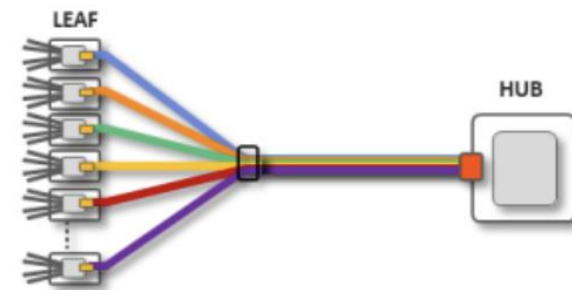
100G/200G/400G P2P

Break-out Mode



4 X 100G LEAFS TO 400G HUB

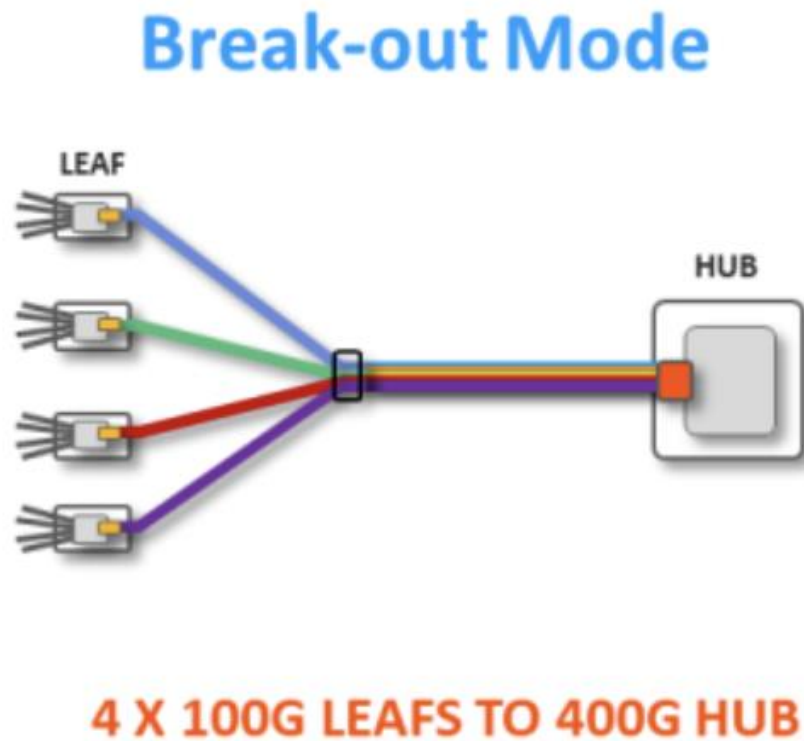
Flexible Point-to-Multipoint



UP TO 16 LEAFS TO 400G HUB

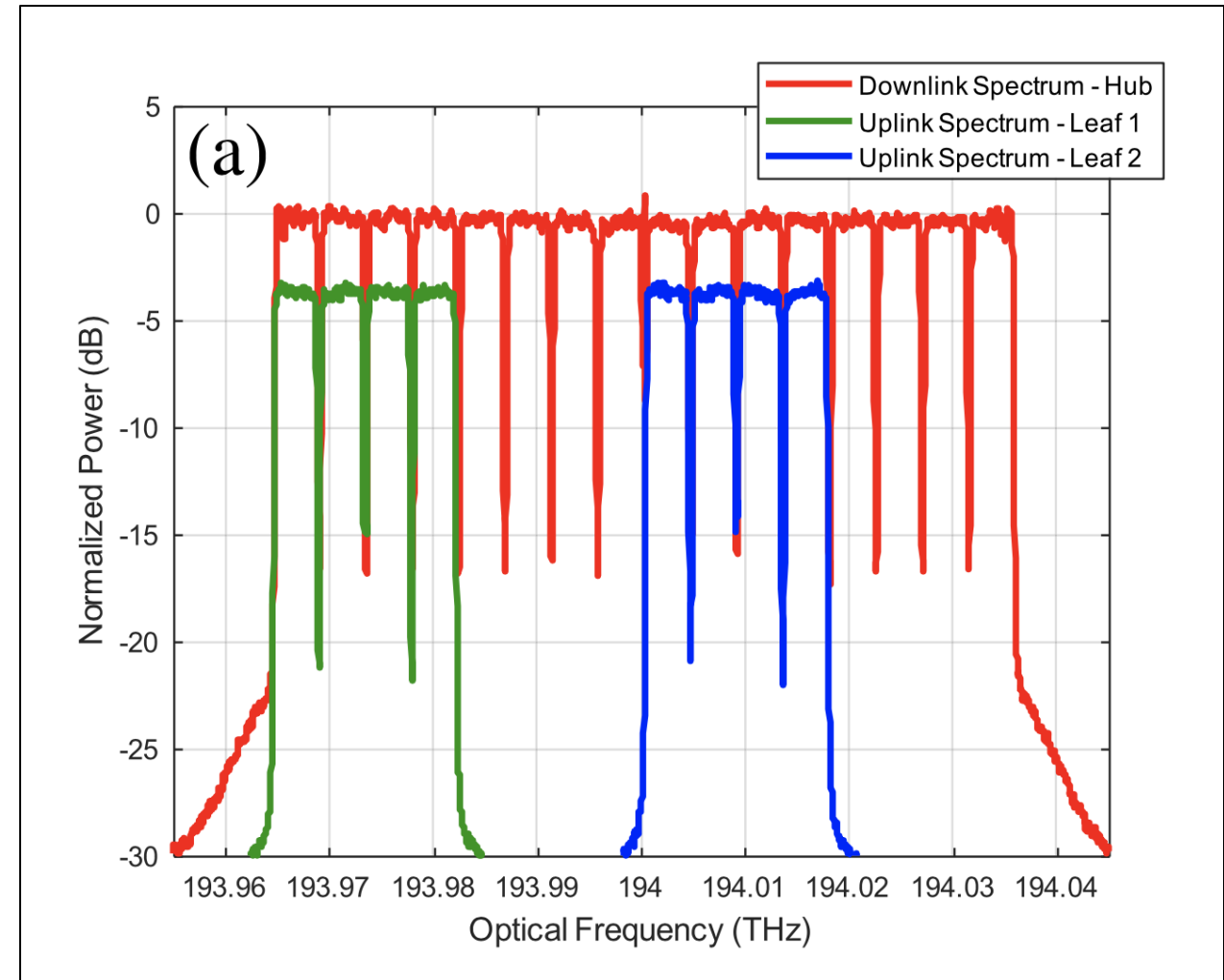
source: [7]

Outlook: DSCM (Digital SubCarrier Multiplexing)



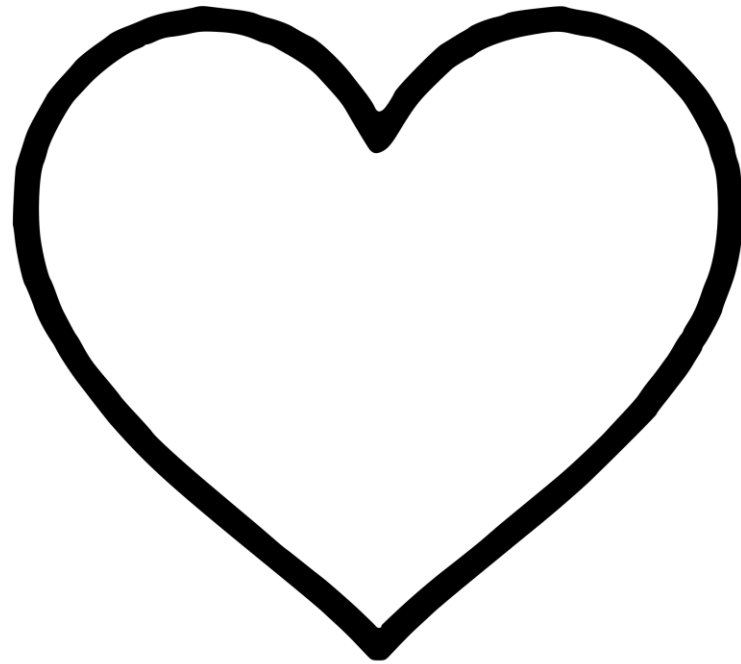
source: [7]

18.01.2024



source: [8]

Thank you!



thomas.weible@flexoptix.net
gerhard.stein@flexoptix.net

References

1. High Speed Transceivers beyond 1.6Tb/s for Data Centre Networks, Osseur 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
3. Lumentum Operations LLC, <https://www.lumentum.com/en/products/400g-zr-zr-qsfp-dd-dco> (accessed Nov. 2023)
4. 400G ZR(+) Real World Examples, Florian Hibler, Arista ; Networks GmbH ; DENOG14 (Nov. 2022)
5. OIF-400ZR-02.0, Implementation Agreement 400ZR, OIFForum; November 3rd of 2022
6. EVOLVING THE AWARENESS OF OPTICAL NETWORKS, Infinera Corporation, <https://www.infinera.com/wp-content/uploads/Evolving-the-Awareness-of-Optical-Networks-0179-WP-RevA-0519.pdf> (Accessed Nov 2023)
7. Digital Subcarrier Multiplexing: Enabling Software-Configurable Optical Networks, Dave Welch et. Al. February 15th of 2023, JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 41, NO. 4
8. SFF-8024, SFF Module Management Reference Code Tables, Rev. 4.10, November 24th of 2022