

Coherent optical transceivers



current capabilities and future possibilities

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]

Summary

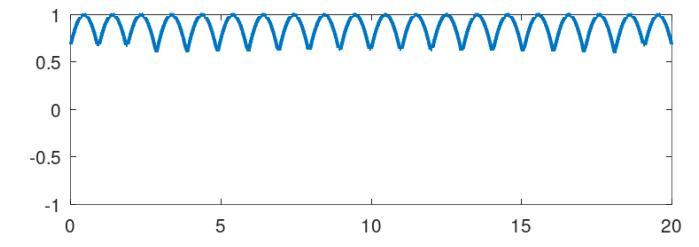
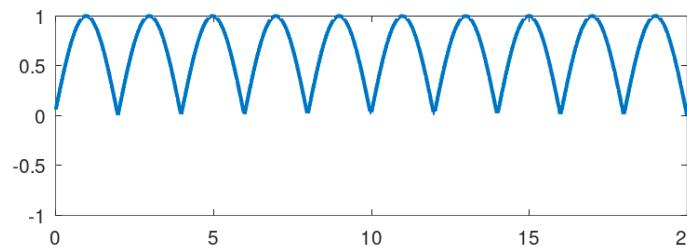
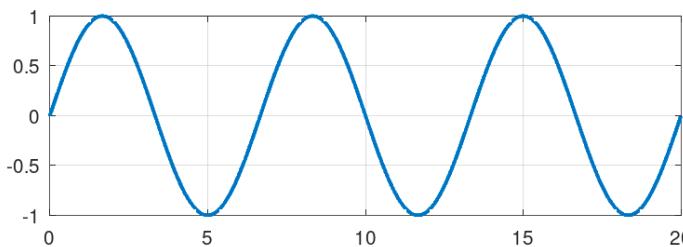
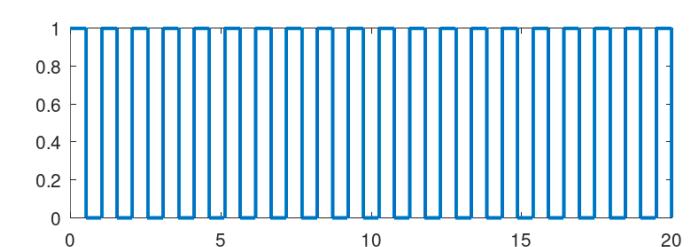
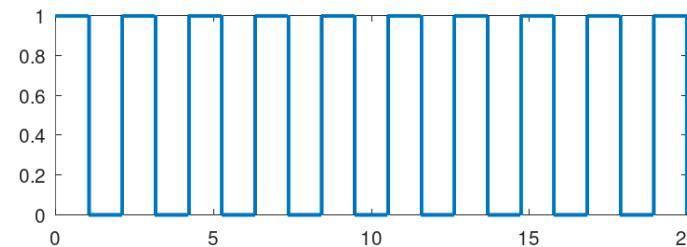
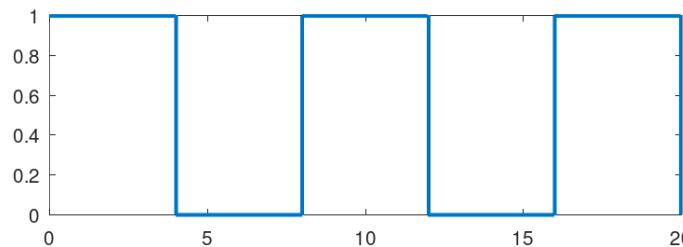
400G-ZR+

- 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

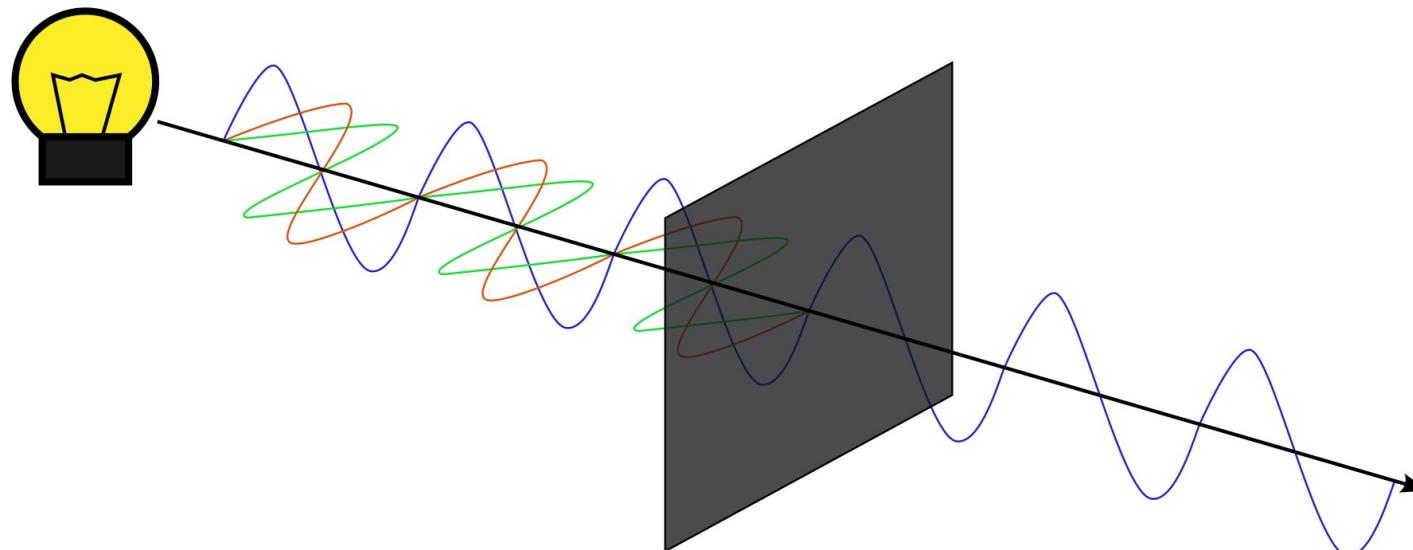
With **higher** frequencies -> harder for Photodiodes to detect signal



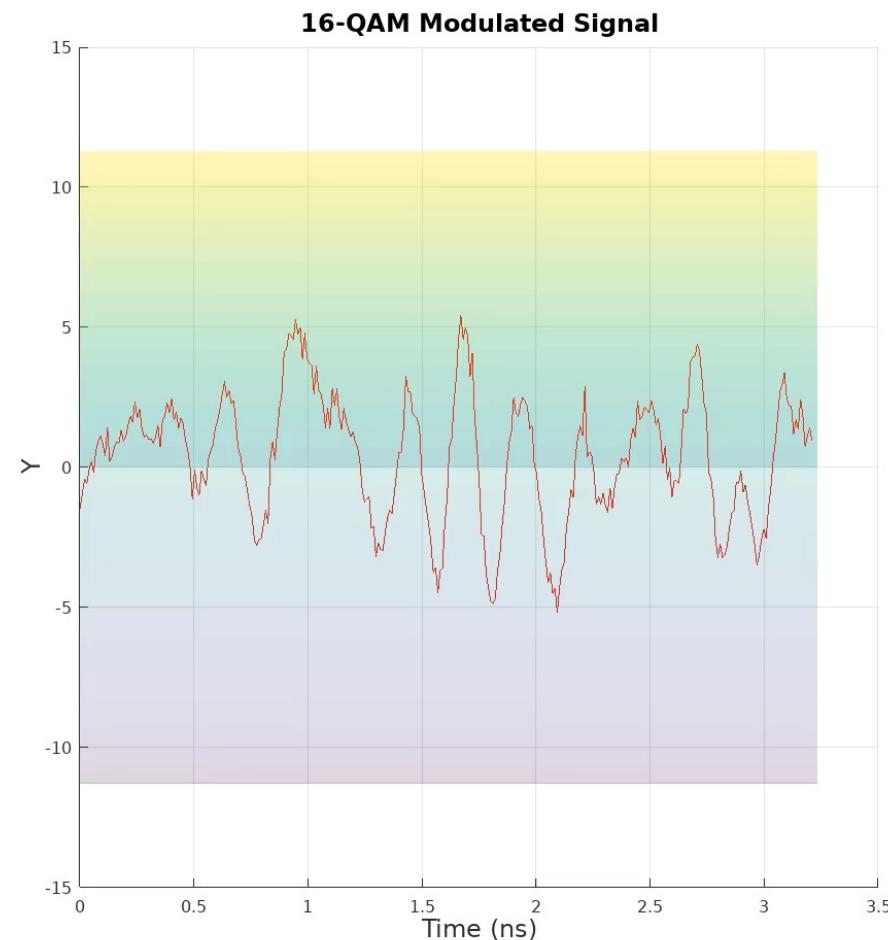
Missed Opportunity: **Light** has more **Properties**

Main Properties of Photonic Waves

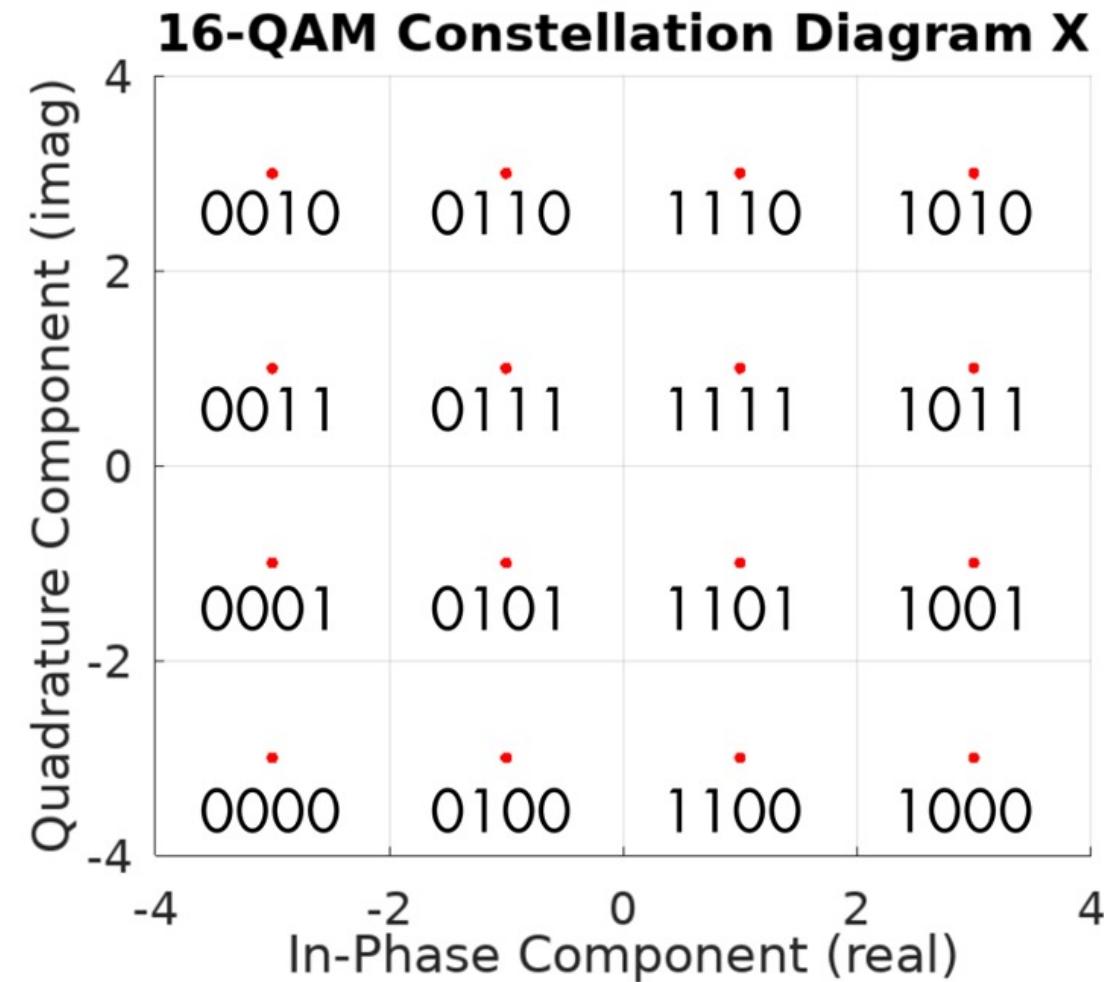
- Besides **Amplitude**, also **Phase** and **Polarisation**
- More properties per Carrier = Higher Bandwidth



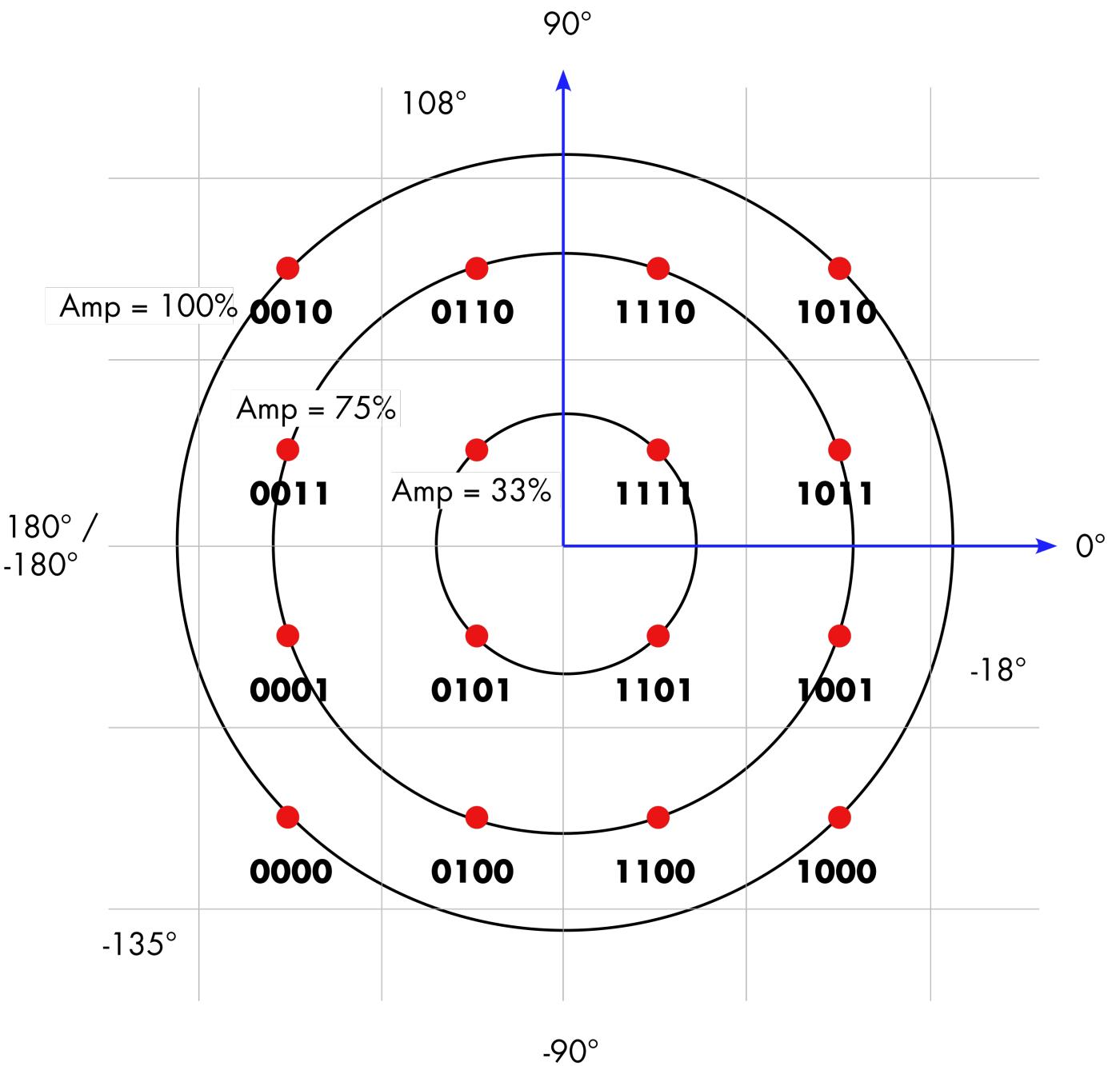
Polarisation Signal on X and Y Plane



Bit Sequence in 16QAM



1111 0101 0111

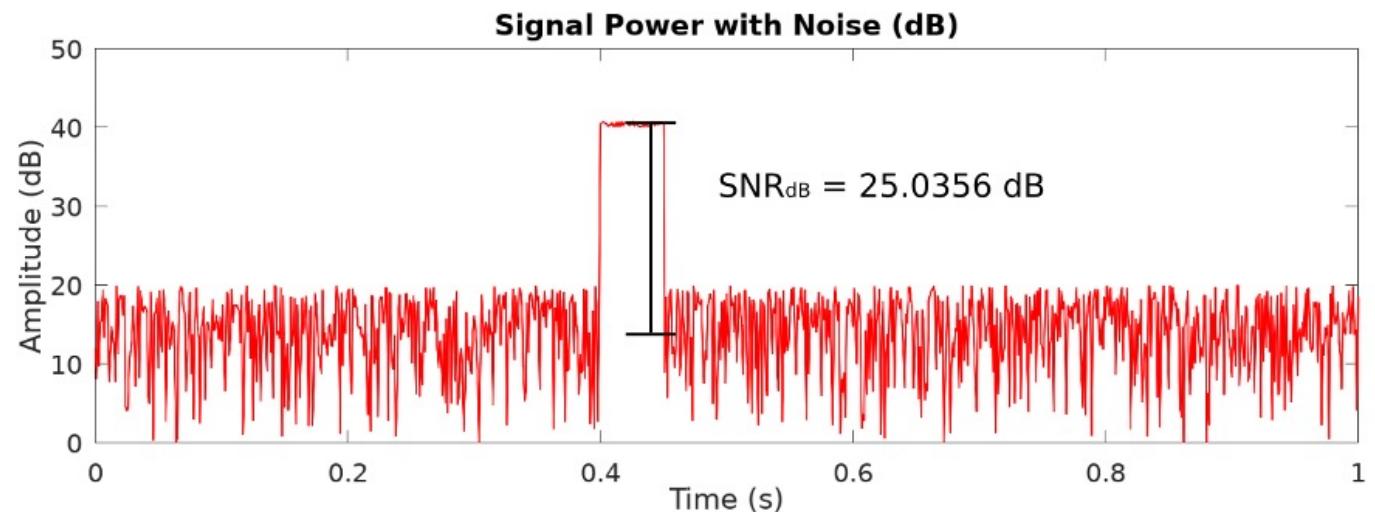


Bit Error Rate:

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

Measuring Signal Quality

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

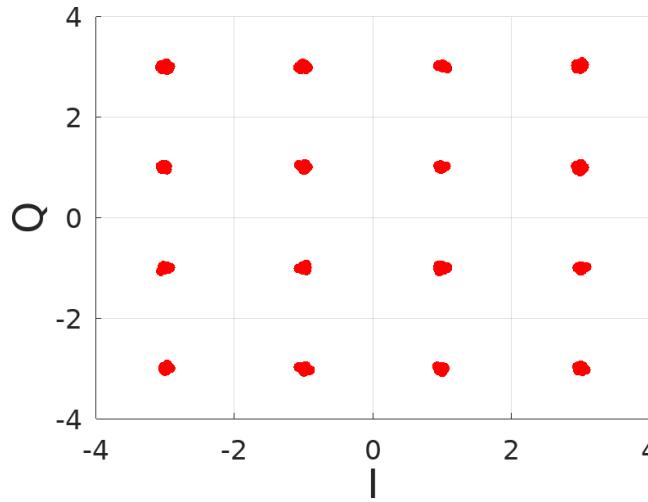


Bit Error Ratio or Bit Error Rate:

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

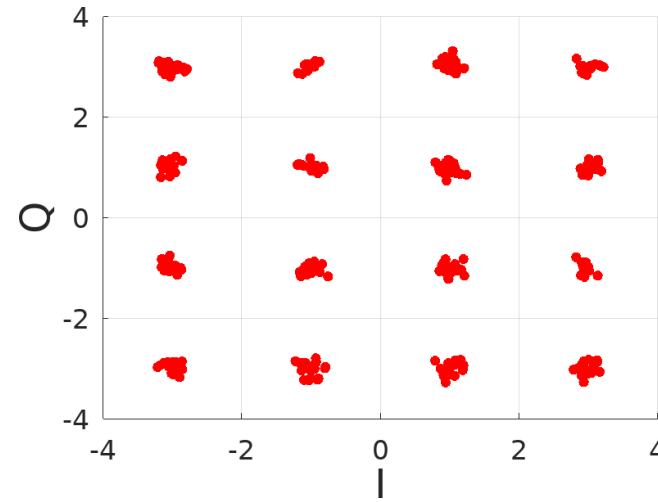
Phase and Amplitude Errors

16-QAM Constellation



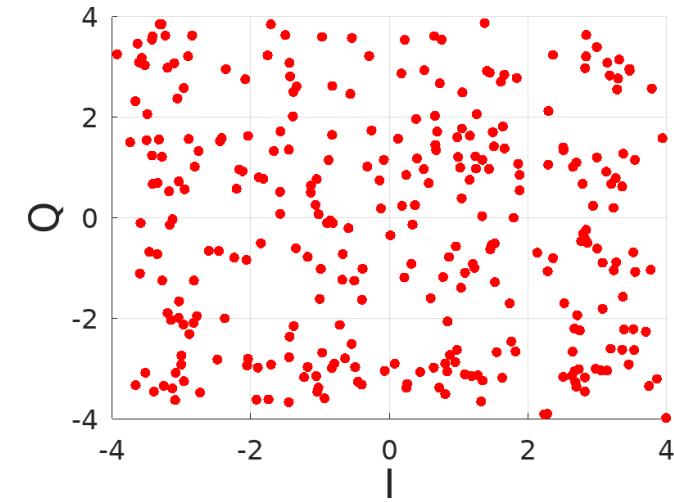
SNR = 30 dB

16-QAM Constellation



SNR = 20 dB

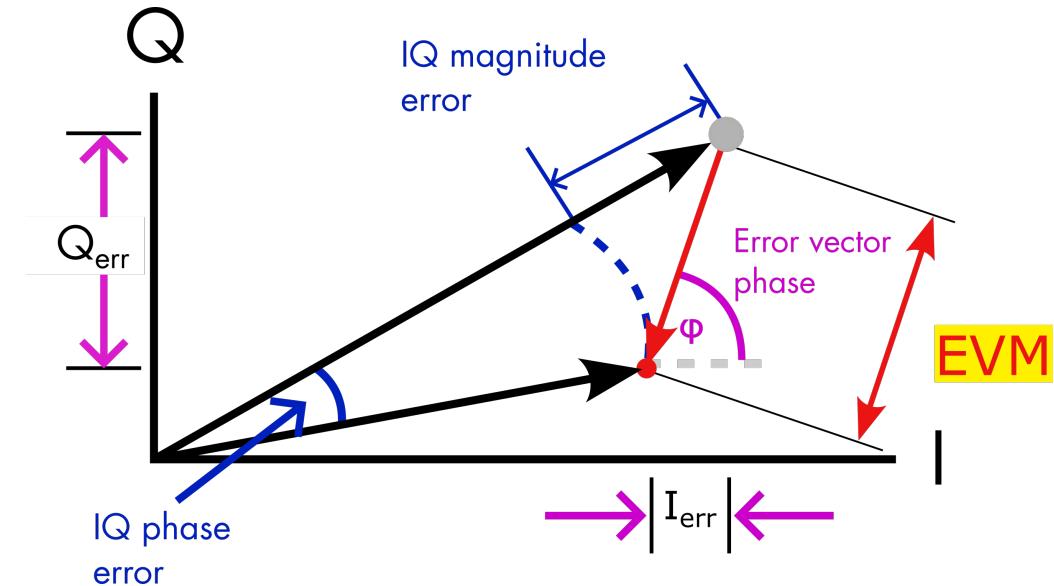
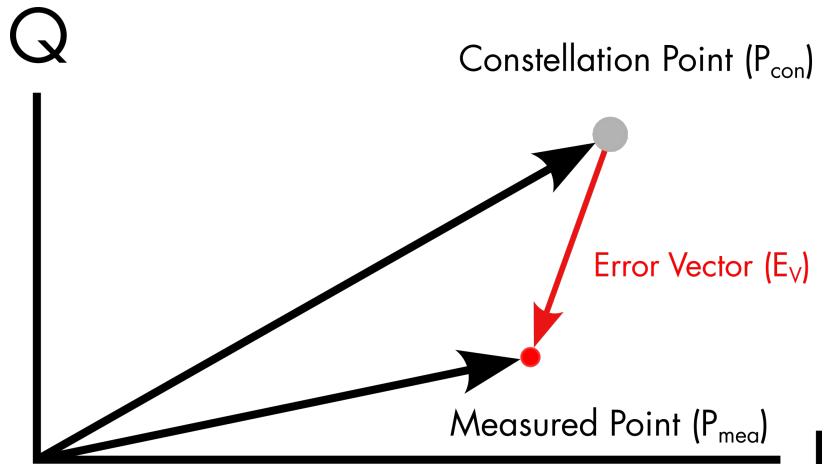
16-QAM Constellation



SNR = 5 dB

NOTE: Polarisation Error not considered

Error Vector Magnitude



$$\text{EVM} = |\overrightarrow{E_V}| = \left| \overrightarrow{P_{con}} - \overrightarrow{P_{mea}} \right|$$

$P_{con} \rightarrow \text{Constellation Point}$
 $P_{mea} \rightarrow \text{Measured Point}$
 $E_V \rightarrow \text{Error Vector}$

NOKIA SR-OS and 400G ZR Transceiver



+



=

terrific
coherent
workshop

source: Daniel Melzer; DE-CIX

source: <https://www.flexoptix.net/en/d-co164hg-2-xt.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 INUIAPHAA  
TX Laser Wavelength: 1558.983 nm  
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  
...  
Optical Compliance : 400G-ZR-Amp 400G-ZR-Unamp  
Link Length support: Unknown  
...
```

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
```

```
Cfg Rx LOS Thresh : -23.00 dBm
```

```
Present Rx Channel : 23
```

```
Cfg Rx Channel : 23
```

required to establish the link, no sweeping

```
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
```

```
Chromatic Disp : 220 ps/nm
```

```
Diff Group Delay : 2 ps
```

```
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  
Cfg Rx LOS Thresh : -23.00 dBm
```

```
Present Rx Channel : 23  
Cfg Rx Channel     : 23
```

```
Disp Control Mode  : automatic  
Cfg Dispersion    :      0 ps/nm
```

```
Sweep Start Disp  : -25500 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
```

```
=====
```

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  
Cfg Rx LOS Thresh : -23.00 dBm
```

```
Disp Control Mode : automatic  
Cfq Dispersion   : 0 ps/nm
```

```
Present Rx Channel : 23  
Cfg Rx Channel    : 23
```

```
Sweep Start Disp  : -25500 ps/nm  
Sweep End Disp   : 2000 ps/nm  
Rx LOS Reaction  : squelch
```

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

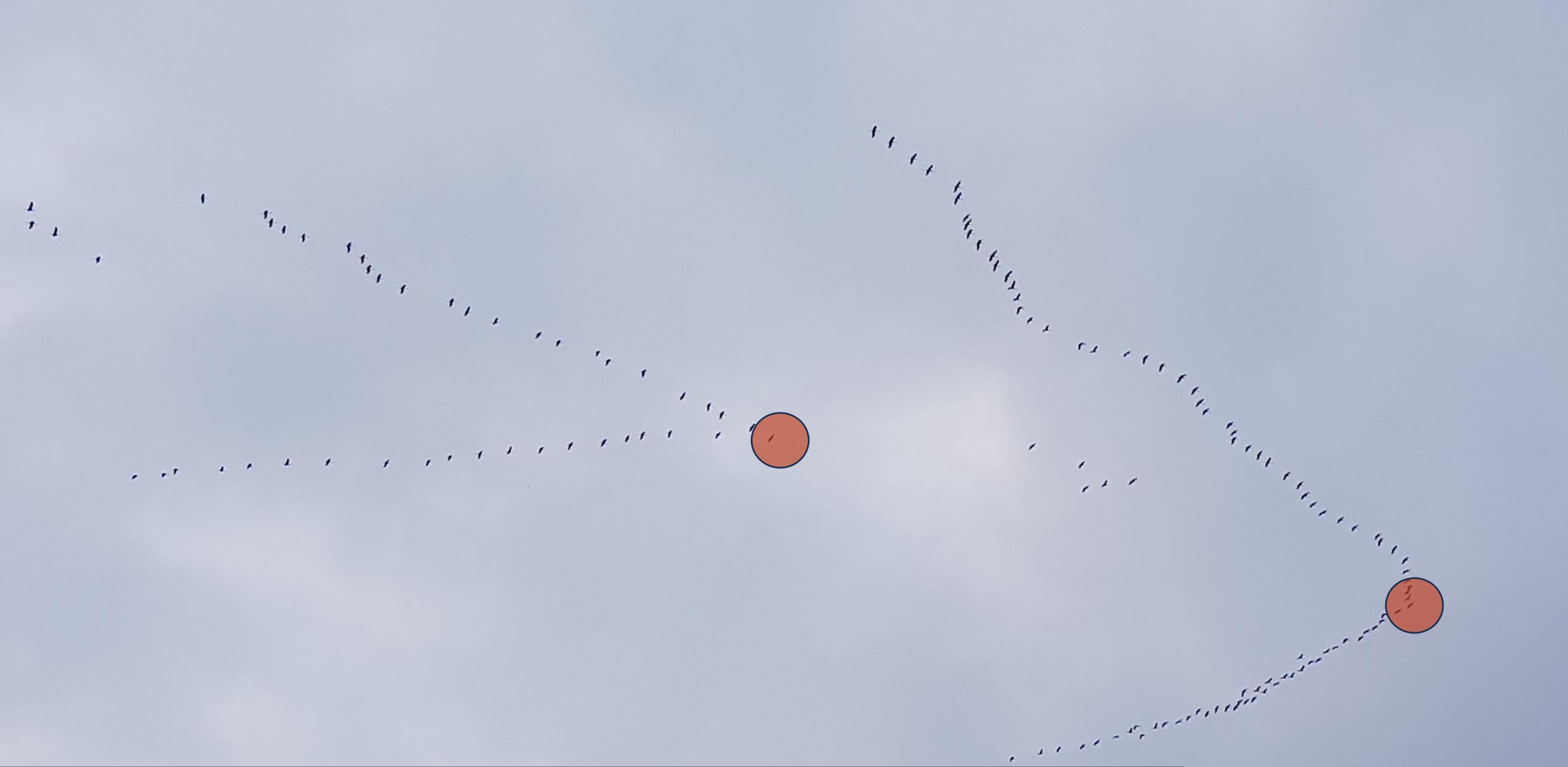
```
hosttx
```

```
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

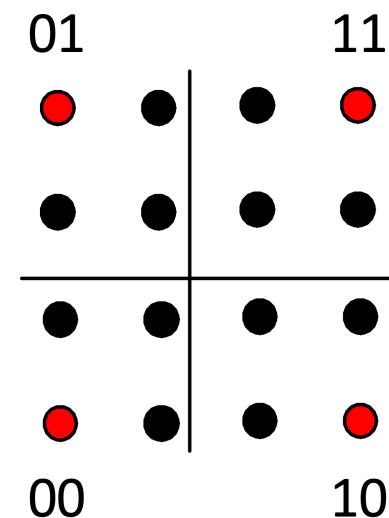
Disp Control Mode : automatic
Cfg Dispersion : 0 ps/nm
CPR Window Size : 32 symbols
Compatibility : openZrpOfec1
Cfg Tx Power Min : -22.90 dBm

Cfg Alarms : modflt mod netrx nettx ho
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 outputP
Rx Turn-Up States : init laserReady waitForIr
                     demodLock
=====
```

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



source: [5]

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 host

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

Diff Group Delay : 2 ps

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
 Cfg Rx LOS Thresh : -23.00 dBm

Present Rx Channel : 23
 Cfg Rx Channel : 23

Disp Control Mode : automatic
 Cfg Dispersion : 0 ps/nm
 CPR Window Size : 32 symbols
Compatibility : openZrpOfec1

Sweep Start Disp : -25500 ps/nm
 Sweep End Disp : 2000 ps/nm
 Rx LOS Reaction : squelch

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-aui2	2x 100GAUI-2 (2x 50G)	oFEC	DP-QPSK	60.1GBd
10	OpenZR+ MSA	openZrpOfec2	1x 100GBASE-R	c1-100g-aui2	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-aui2	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, !??

2

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

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	openZrpOfec2
11	OpenZR+ MSA	openZrpOfec1
12	OpenZR+ MSA, Enhanced	
13	OIF 400ZR, amplified	oif-400g-zr
14	OpenZR+ MSA, Enhanced	openZrpOfec2
15	OpenZR+ MSA	

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

FEC	Modulation	Line Symbol Baud Rate
CFEC	DP-16QAM	59.8GBd
CFEC	DP-16QAM	59.8GBd
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

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-LR (Clause 52)	42.310	4	10.3125	PAM4	2
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

PUBLISHED

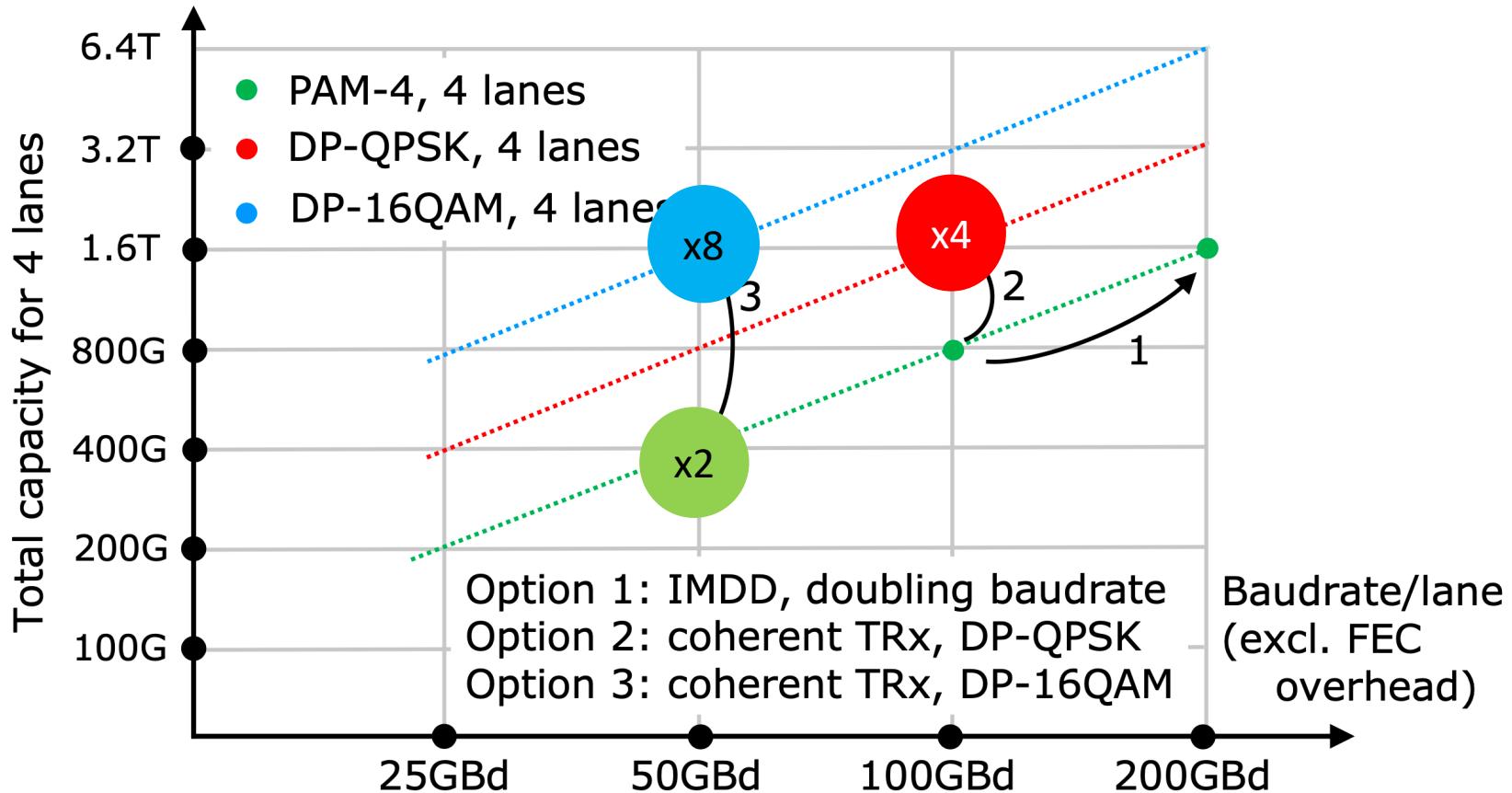
ID	ID (Hex)	SM Media Interface (Specification Reference)
0	0	Undefined
		Ethernet
1	1	10GBASE-LW (Clause 151)
2	2	10GBASE-EW (Clause 151)
3	3	10G-ZW
4	4	10GBASE-LR (Clause 151)
5	5	10GBASE-LR (Clause 151)
29	1D	400G-FR4 MSA FR4 (Clause 151)
67	43	400GBASE-LR4-6 (Clause 151)
30	1E	400G-LR4-10 MSA Spec ²
77	4D	400GBASE-ZR (Clause 156)
86	56	800GBASE-DR8 (placeholder)
87	57	800GBASE-DR8-2 (placeholder)

PUBLISHED

SFF-8024 Rev 4.10

ID	ID (Hex)	SM Media Interface (Specification Reference)	Application Bit Rate, Gb/s	Lane Count	Lane Signaling Rate, GBd	Modula-tion	b/UI
		OIF					
62	3E	400ZR, DWDM, amplified	478.75	1	59.84375	DP-16QAM	8
63	3F	400ZR, Single Wavelength, Unamplified	478.75	1	59.84375	DP-16QAM	8
		OpenZR+					
70	40	ZR400-O FEC-16QAM	481.108374	1	60.1385468	DP-16QAM	8
71	41	ZR300-O FEC-8QAM	360.831281	1	60.1385468	DP-8QAM	6
72	42	ZR200-O FEC-QPSK	240.554187	1	60.1385468	DP-QPSK	4
73	43	ZR100-O FEC-QPSK	120.277094	1	30.069273	DP-QPSK	4
53-55	55-57	Reserved					
88-191	58-BF	Reserved					

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



source: [1]

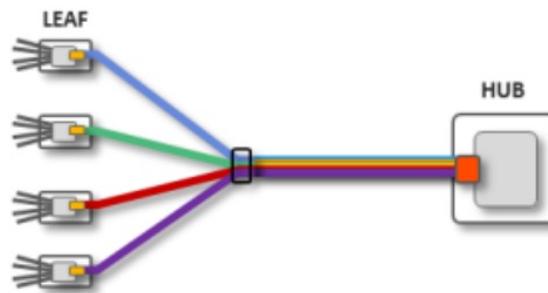
Outlook: OpenXR 16 x 25Gbit/s via DSCM

Point-to-Point



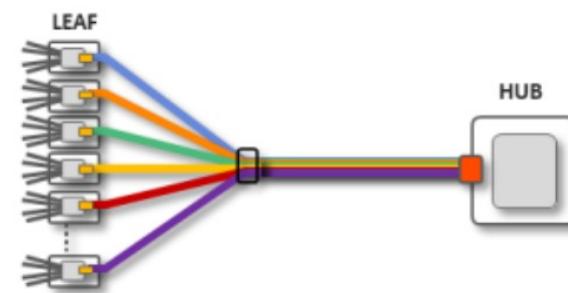
100G/200G/400G P2P

Break-out Mode



4 X 100G LEAFS TO 400G HUB

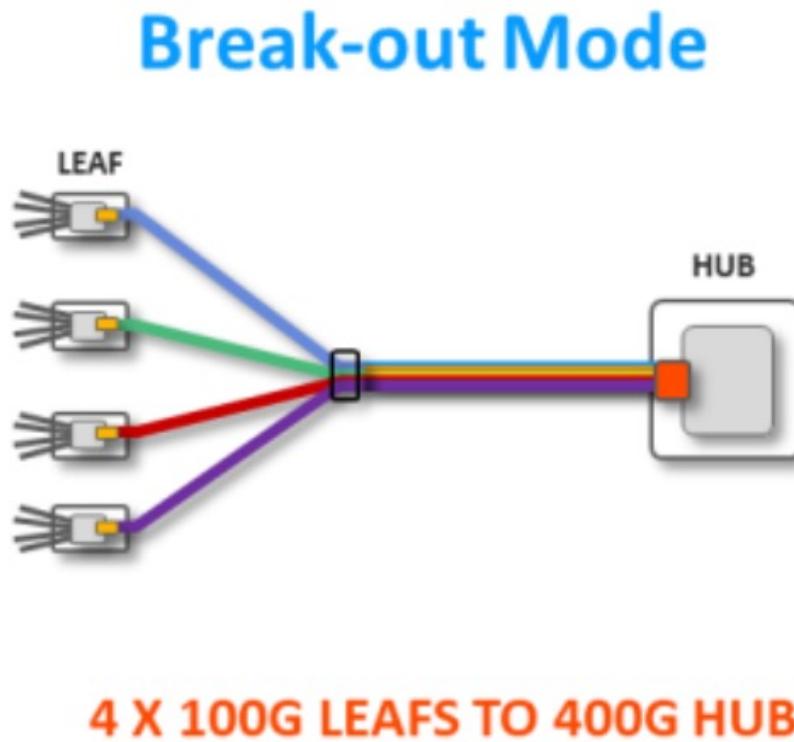
Flexible Point-to-Multipoint



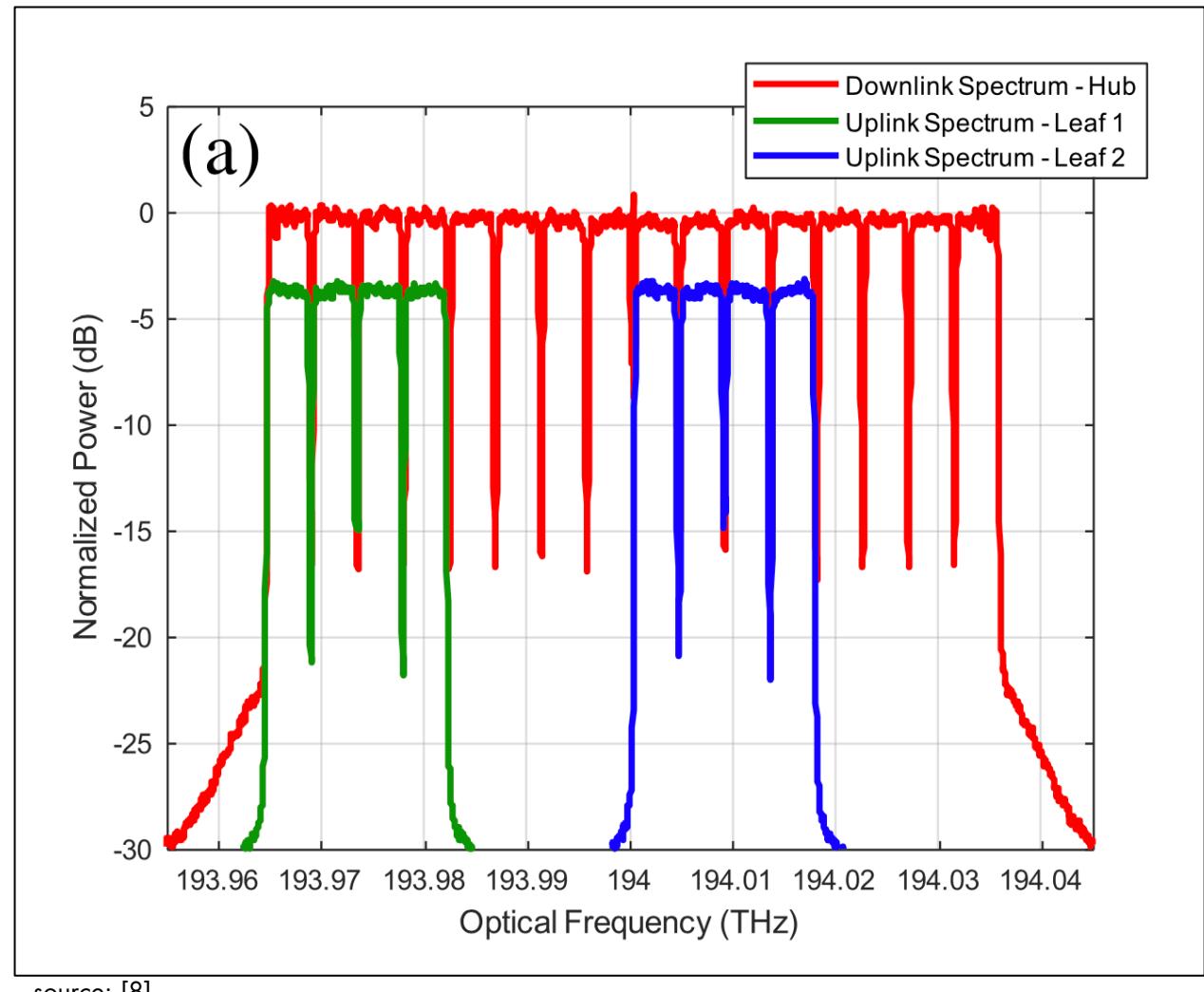
UP TO 16 LEAFS TO 400G HUB

source: [7]

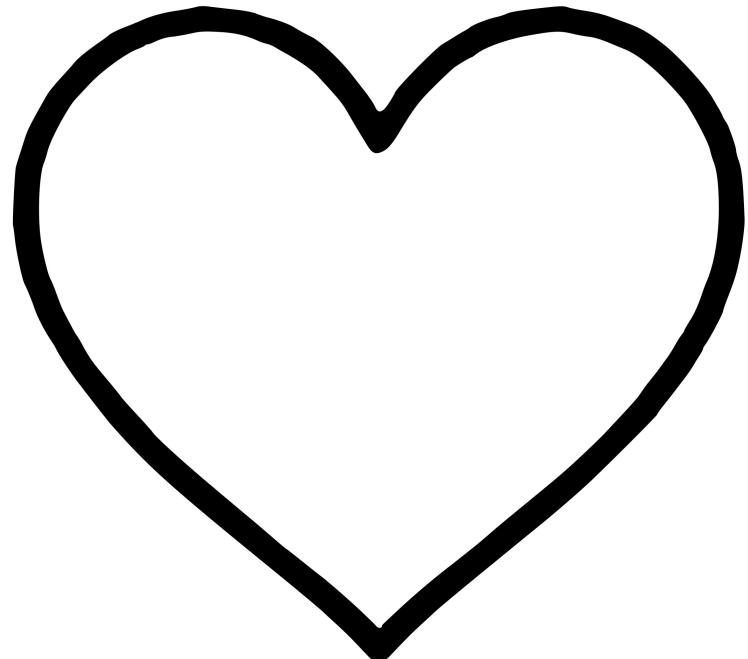
Outlook: DSCM (Digital SubCarrier Multiplexing)



source: [7]



Thank you!



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