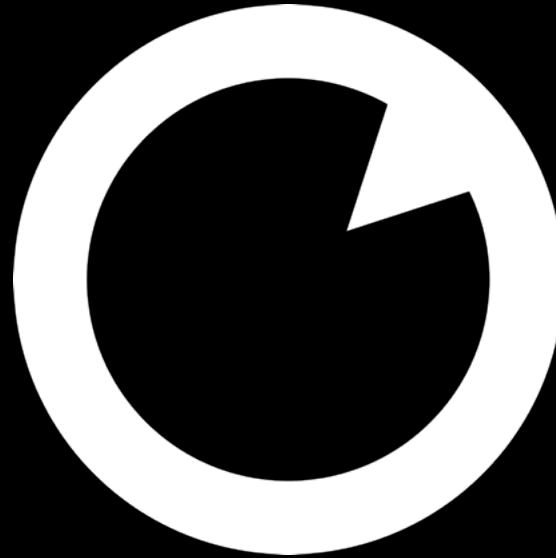


Coherent optical transceivers



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

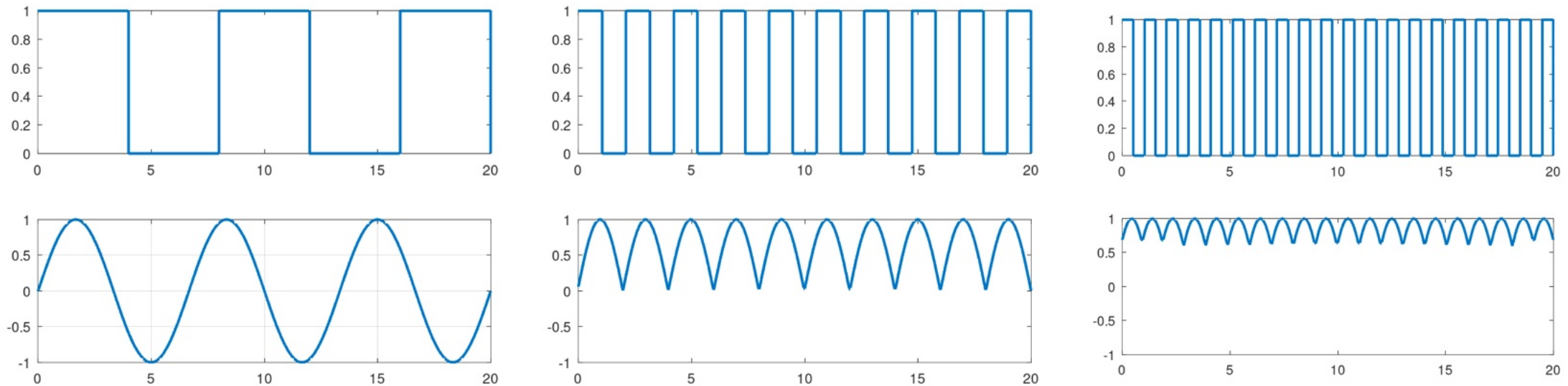
 Using those transceiver in unsupported platforms could irreversibly damage your device!

- 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

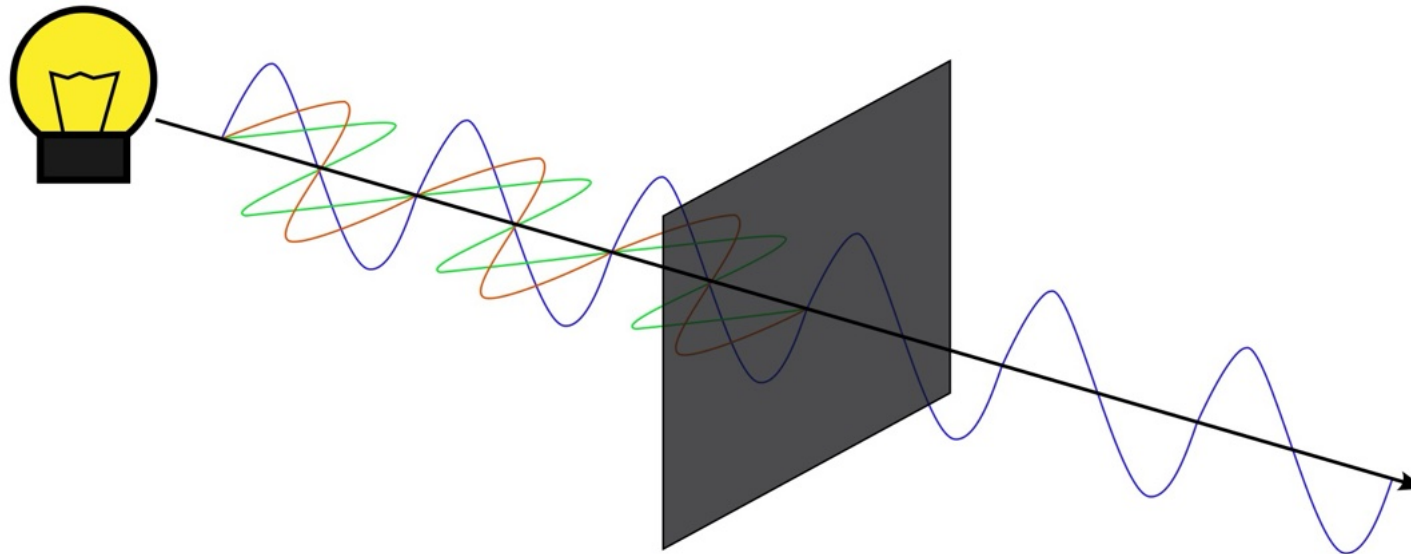
With **higher** frequencies -> harder for Photodiodes to detect signal



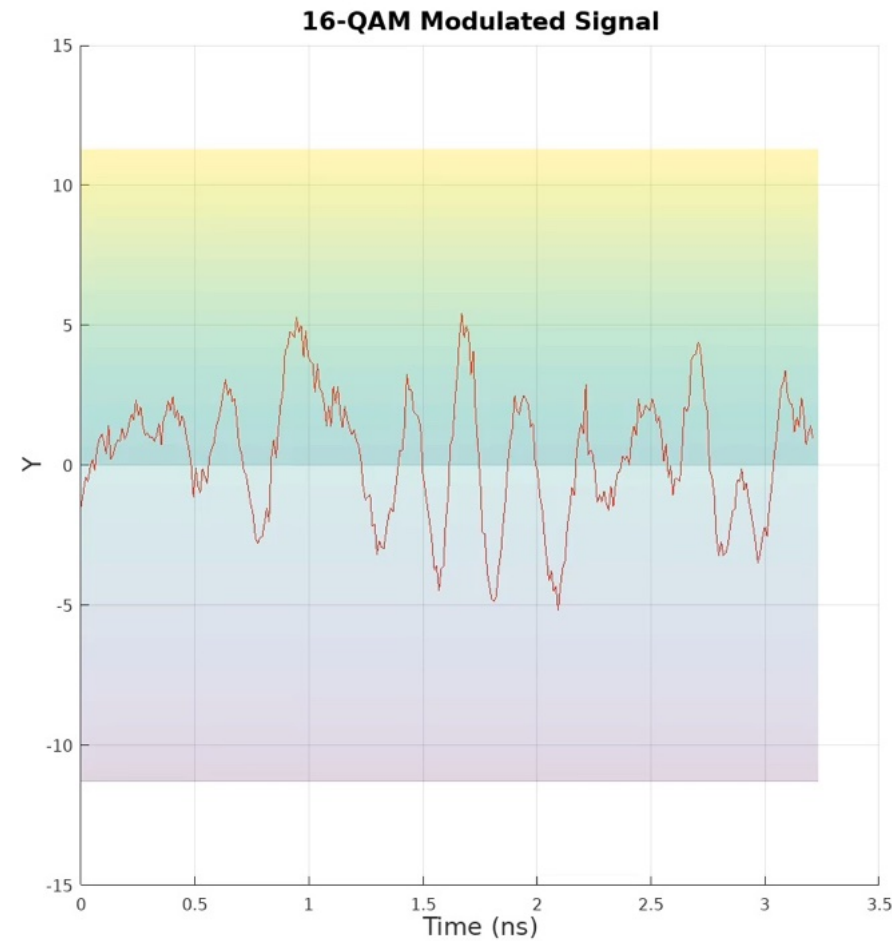
Missed Opportunity: **Light** has more **Properties**

Main Properties of Photonic Waves

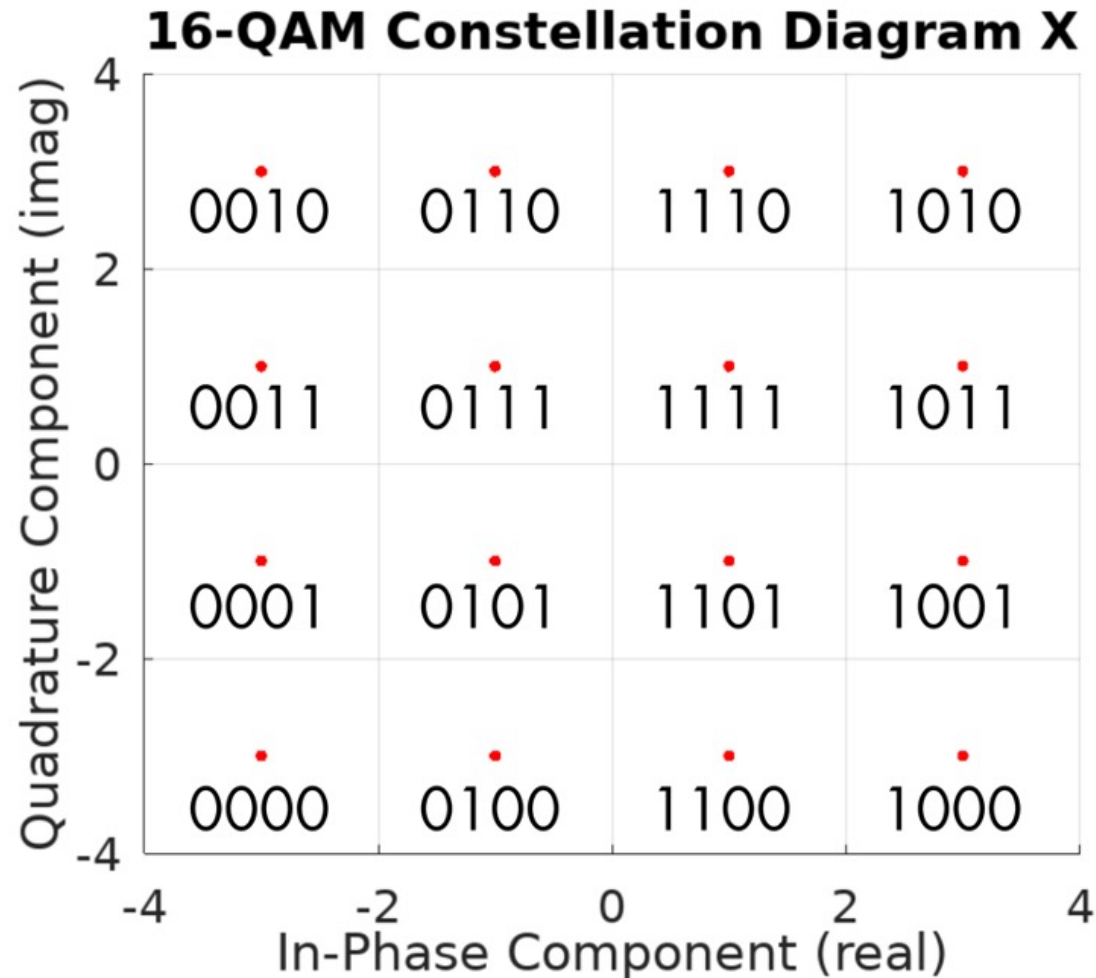
- Besides **Amplitude**, also **Phase** and **Polarisation**
- More properties per Carrier = Higher Bandwidth



Polarisation Signal on X and Y Plane



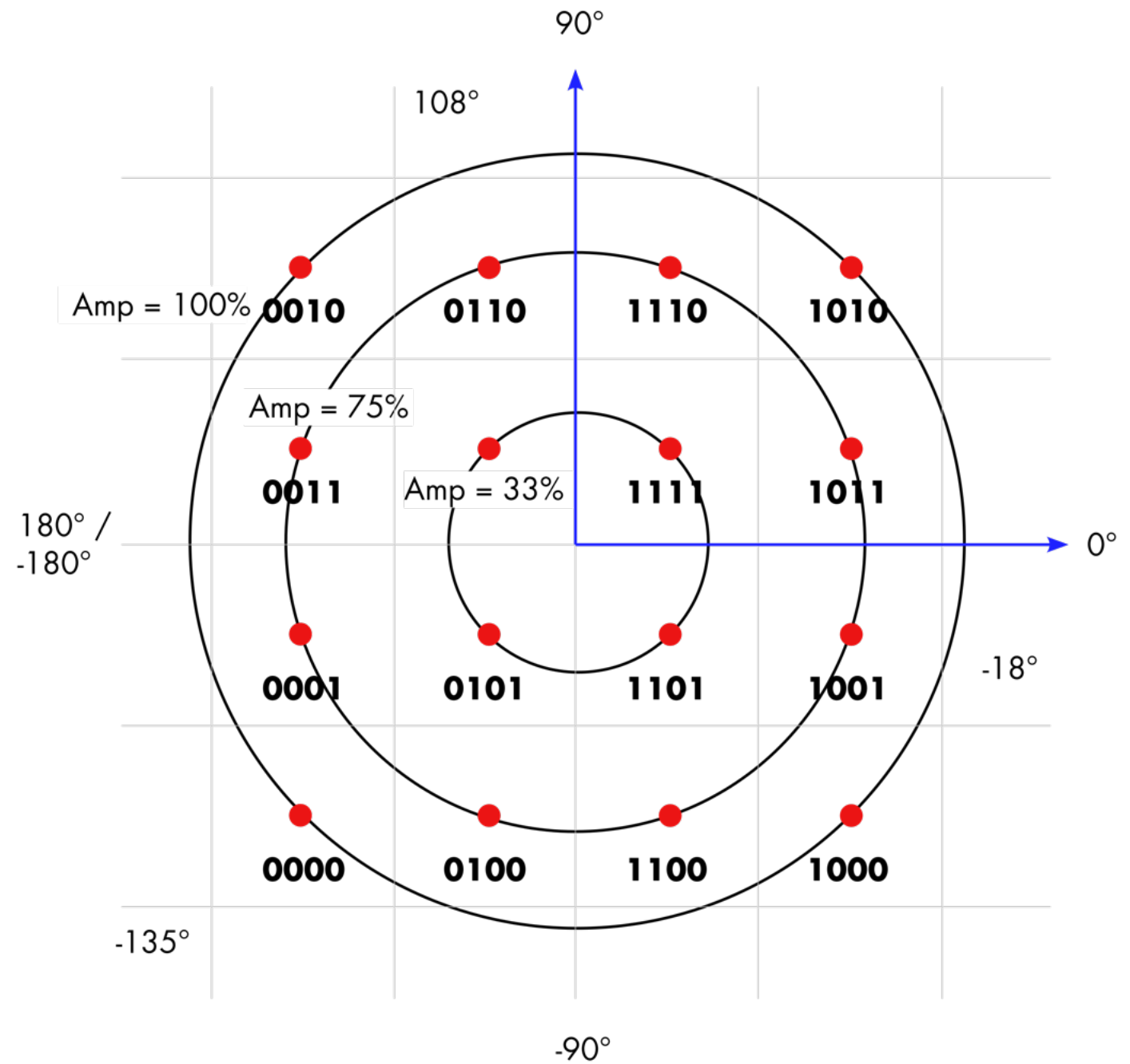
Bit Sequence in 16QAM



1111 0101 0011

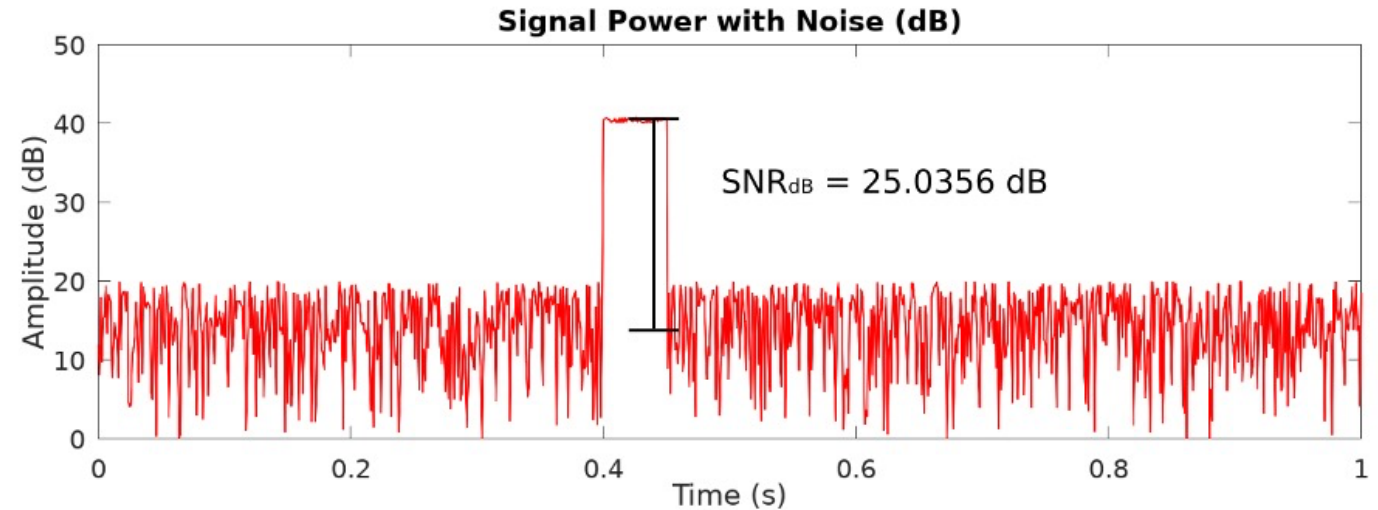
Bit Error Rate:

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



Measuring Signal Quality

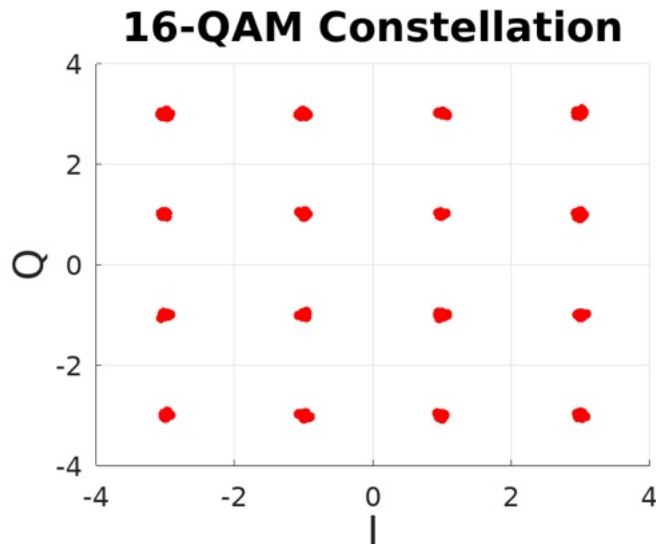
- **SNR** = Signal-to-Noise-Ratio
- Convenience of using decibels for **small** and **large** values
- (e)SNR vs OSNR :
electrical vs **optical**



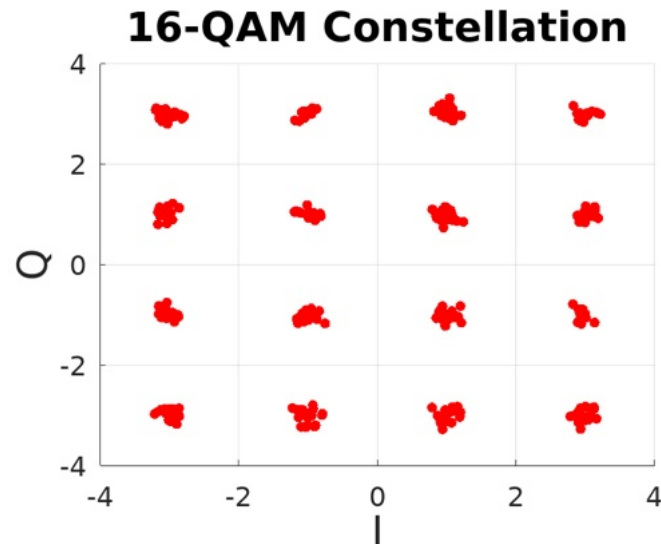
Bit Error Ratio or Bit Error Rate:

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

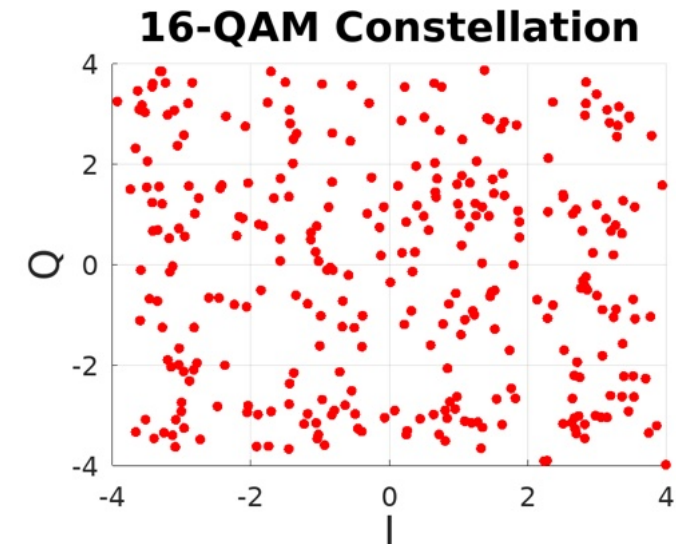
Phase and Amplitude Errors



SNR = 30 dB



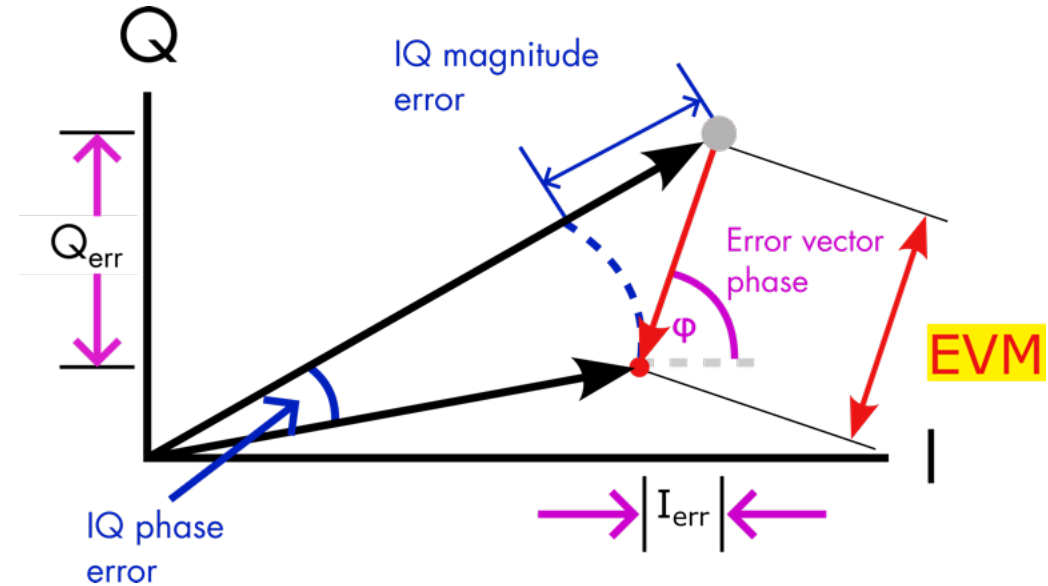
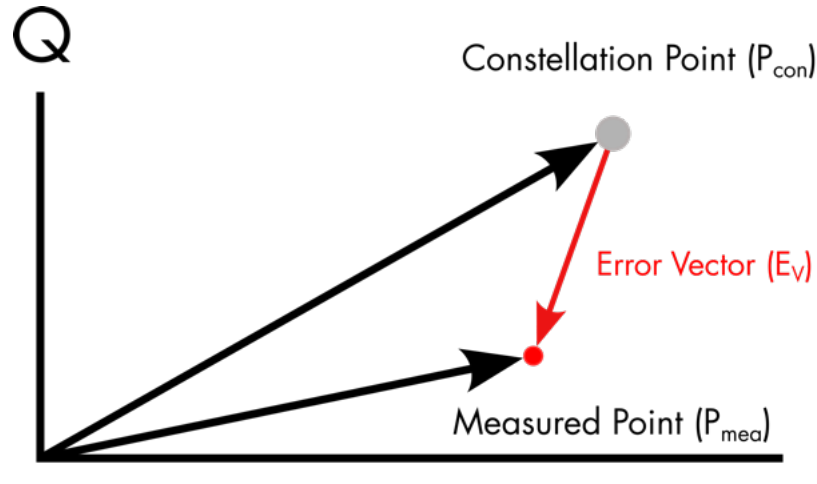
SNR = 20 dB



SNR = 5 dB

NOTE: Polarisation Error not considered

Error Vector Magnitude



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

$P_{con} \rightarrow$ Constellation Point

$P_{mea} \rightarrow$ Measured Point

$E_V \rightarrow$ 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>

```
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                      DCO                      : Enabled
Model Number       : 3HE16564AARA01  NOK  INUIAPHHAA
TX Laser Wavelength: 1558.983 nm                    Present Channel : 23
                                                    Configured Chann*: 23

Laser Tunability   : flex-tunable
Config Freq (MHz)  : 0                            Min Freq (MHz)   : 191300000
Oper Freq (MHz)    : 192300000                     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
...
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
---	---	---	-------	----------

```
=====
```

...

```

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       : openZrp0fec1
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
=====

```

```

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
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          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

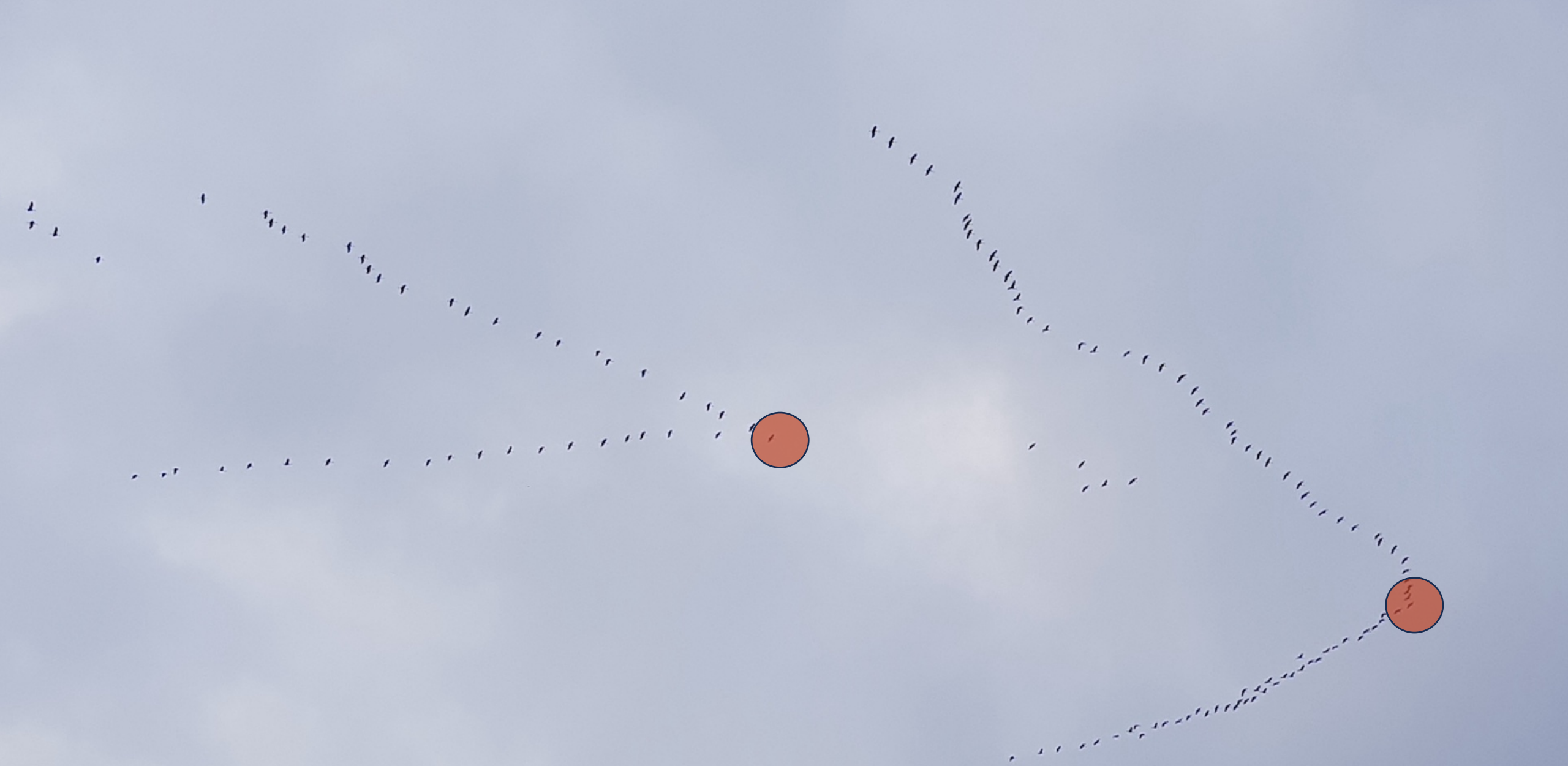
Chromatic Disp      :    220 ps/nm
Diff Group Delay    :      2 ps
Pre-FEC BER         : 1.213E-03

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

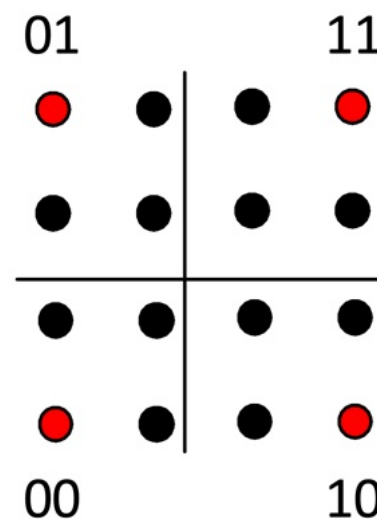
Disp Control Mode   : automatic
Cfg Dispersion      :      0 ps/nm
CPR Window Size     : 32 symbols
Compatibility       : openZrp0fec1
Cfg Tx Power Min    : -22.90 dBm

Cfg Alarms          : modflt mod netrx nettx hc
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 outputF
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.



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      : openZrp0fec1
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

```
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
```

```
Sweep Start Disp  : -25500 ps/nm
Sweep End Disp    : 2000 ps/nm
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      : openZrp0fec1
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

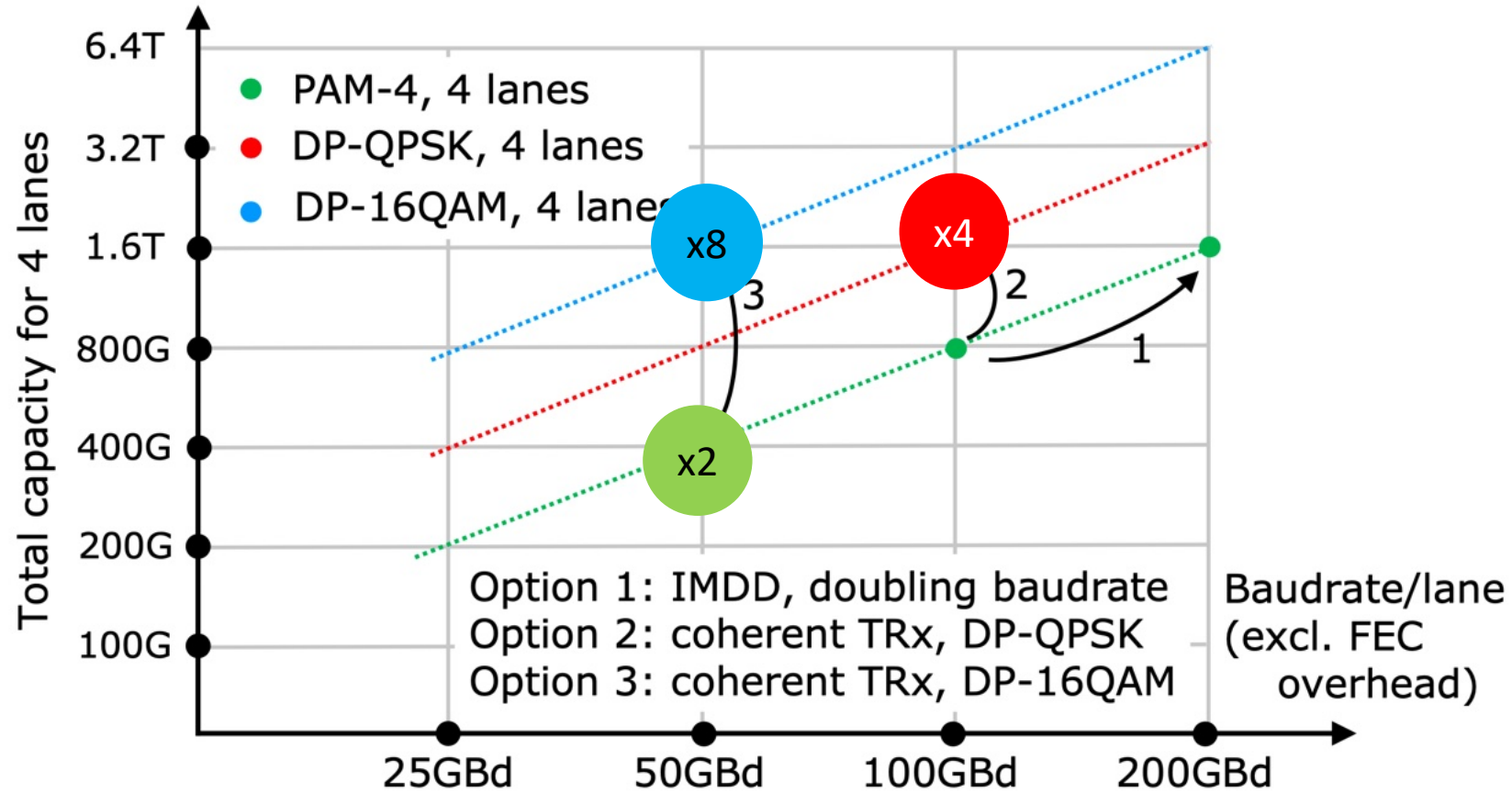
Transceiver Data
...
Laser Tunability : flex-tunable
Config Freq (MHz) : 0
Oper Freq (MHz)   : 192300000
Fine Tune Range   : 6000 MHz
Supported Grids    : 100GHz 75GHz 50GHz 25GHz
...
Optical Compliance : 400G-ZR-Amp 400G-ZR-Unamp
Link Length support: Unknown
...
```

Application Mode	MSA format	Nokia Compatibility				FEC	Modulation	Line Symbol Baud Rate
1	OIF 400ZR, amplified	oif-400g-zr				CFEC	DP-16QAM	59.8GBd
2	OIF 400ZR, unamplified					CFEC	DP-16QAM	59.8GBd
3	OpenZR+ MSA	openZrpOfec1				oFEC	DP-16QAM	60.1GBd
4	OpenZR+ MSA					oFEC	DP-16QAM	60.1GBd
5	OpenZR+ MSA	openZrpOfec1				oFEC	DP-16QAM	60.1GBd
6	OpenZR+ MSA, Enhanced	openZrpOfec2				oFEC	DP-16QAM	60.1GBd
7	OpenZR+ MSA, Enhanced					oFEC	DP-16QAM	60.1GBd
8	OpenZR+ MSA, Enhanced	openZrpOfec2				oFEC	DP-16QAM	60.1GBd
9	OpenZR+ MSA	openZrpOfec1				oFEC	DP-QPSK	60.1GBd
10	OpenZR+ MSA	openZrpOfec1				oFEC	DP-QPSK	30.1GBd
11	OpenZR+ MSA	openZrpOfec1				oFEC	DP-8QAM	60.1GBd
12	OpenZR+ MSA, Enhanced					oFEC	DP-8QAM	60.1GBd
13	OIF 400ZR, amplified	oif-400g-zr				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

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	10GBASE-ER (Clause 52)	10.31	1	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]

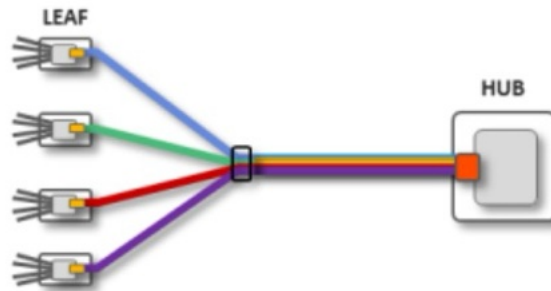
Outlook: OpenXR 16 x 25Gbit/s via DSCM

Point-to-Point



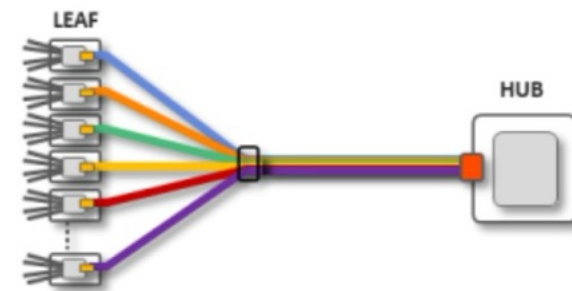
100G/200G/400G P2P

Break-out Mode



4 X 100G LEAFS TO 400G HUB

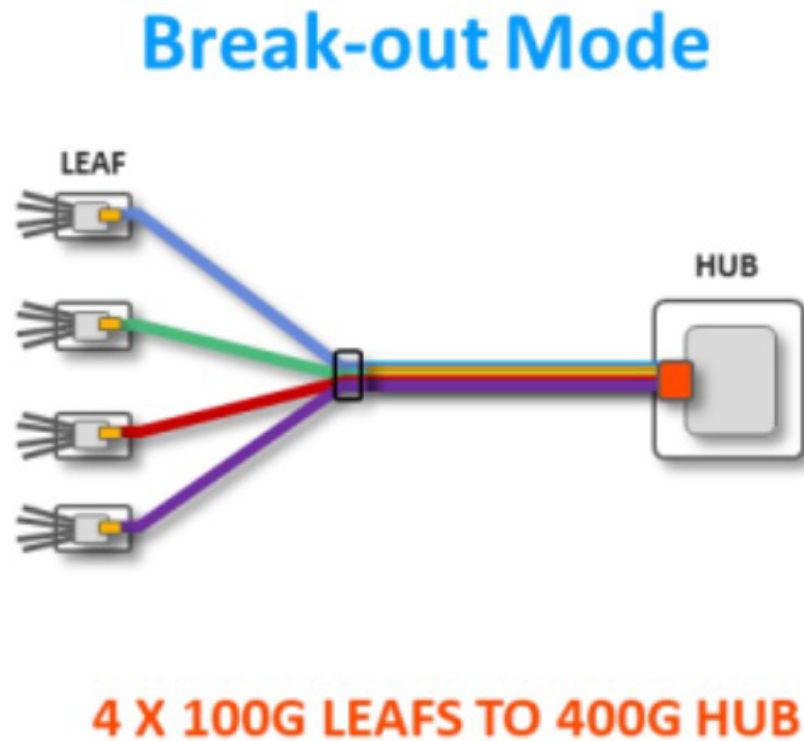
Flexible Point-to-Multipoint



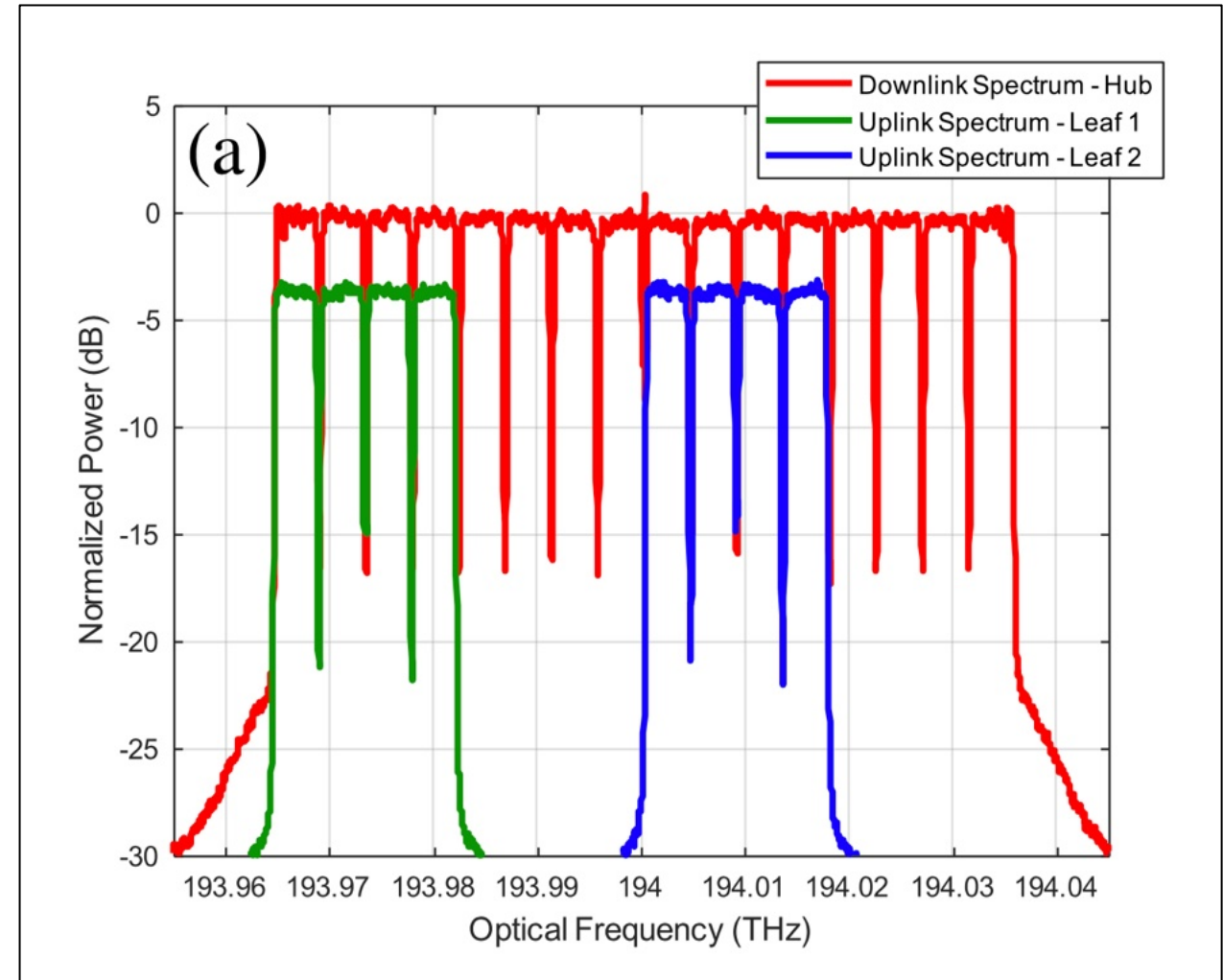
UP TO 16 LEAFS TO 400G HUB

source: [7]

Outlook: DSCM (Digital SubCarrier Multiplexing)



source: [7]



source: [8]

References

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