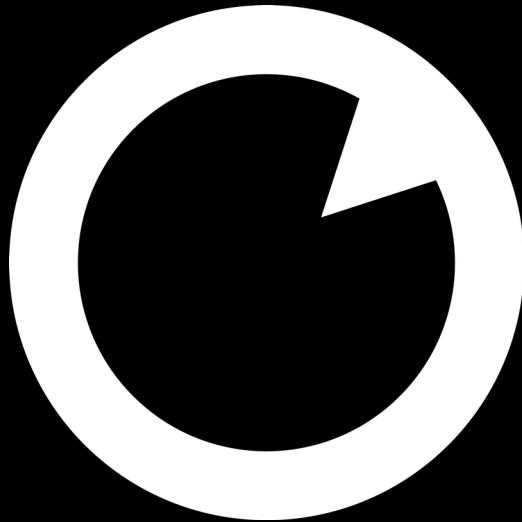


coherent optical transceivers



current capabilities and
future possibilities

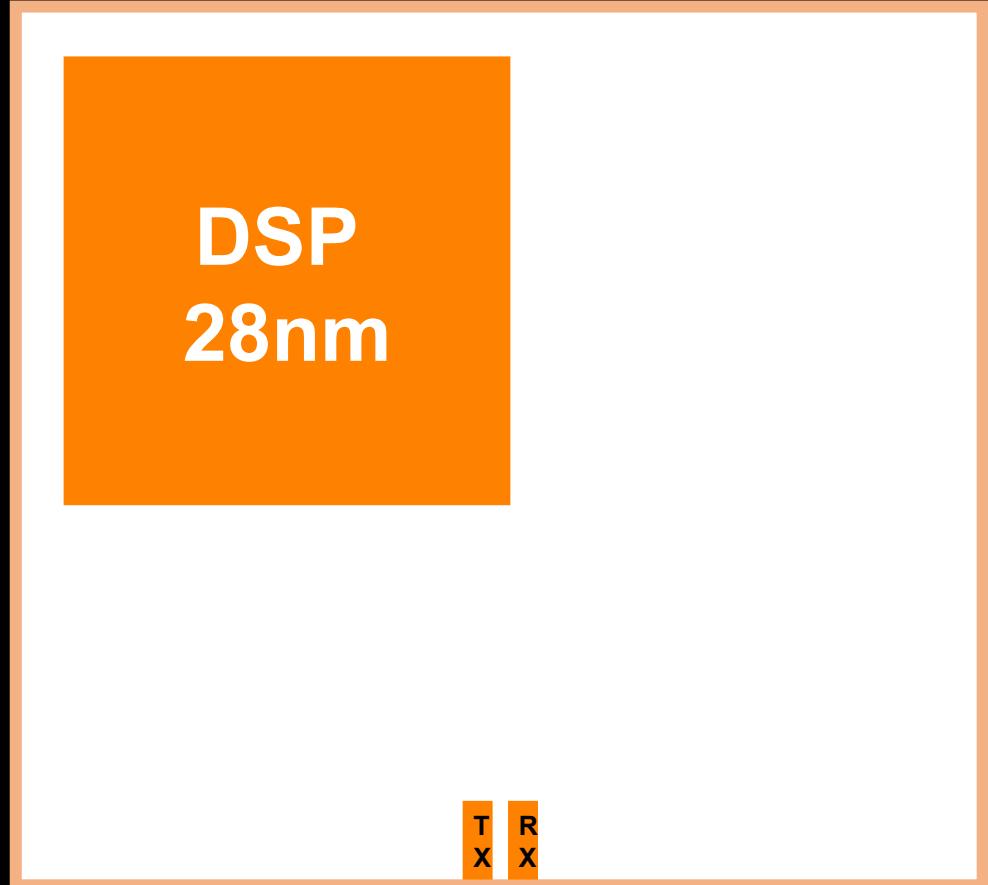
100G ecosystem limits ...



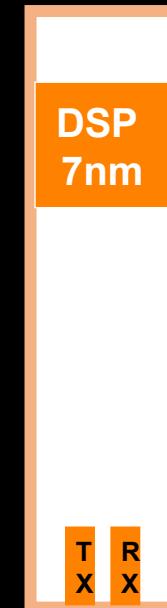
- ratio of power consumption to formfactor
- focus on inner datacenter links
- variation of diverse hardware

... sorted now with 400G

DWDM transponder card

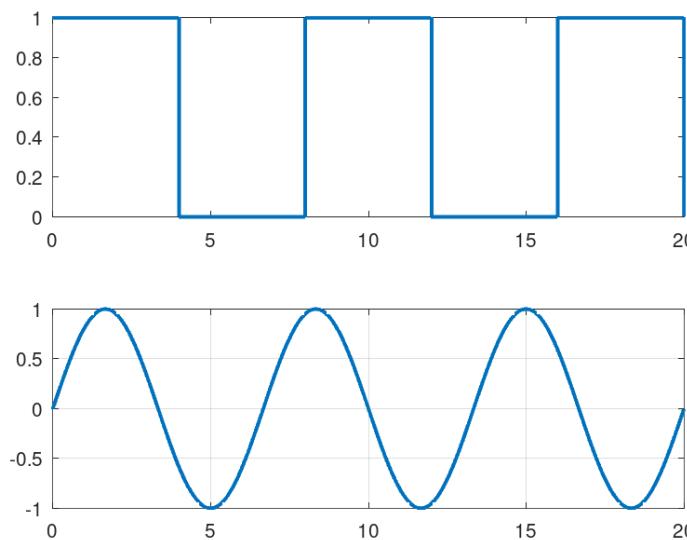


pluggable QSFP-DD



Direct Detection Transceiver limits

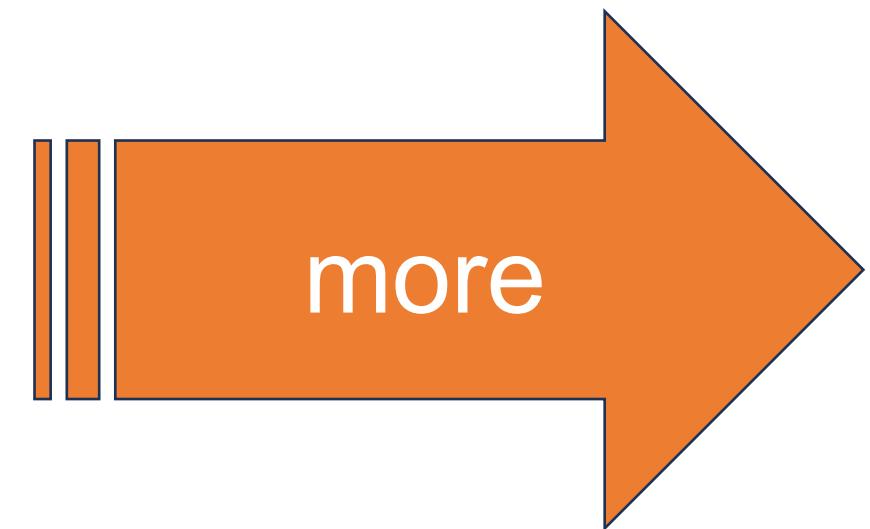
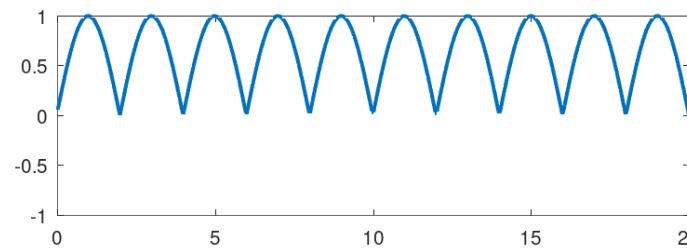
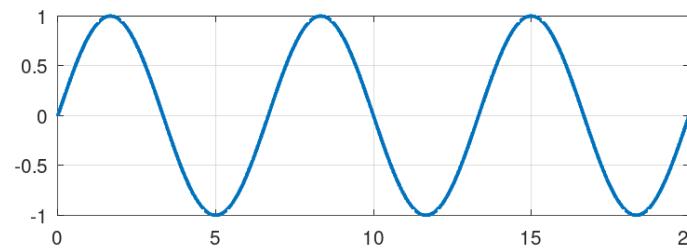
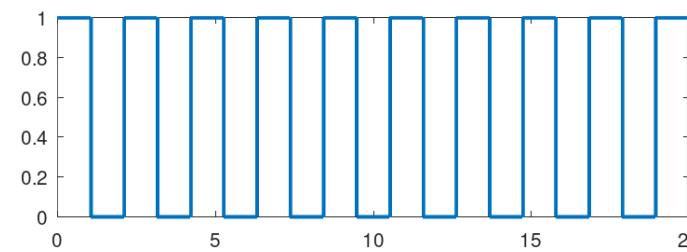
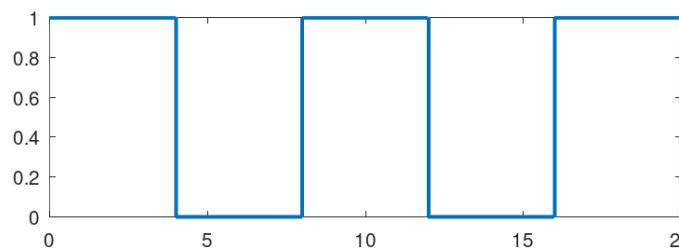
With **higher** frequencies -> harder for Photodiodes to detect



Missed Opportunity: Light has more Properties

Direct Detection Transceiver limits

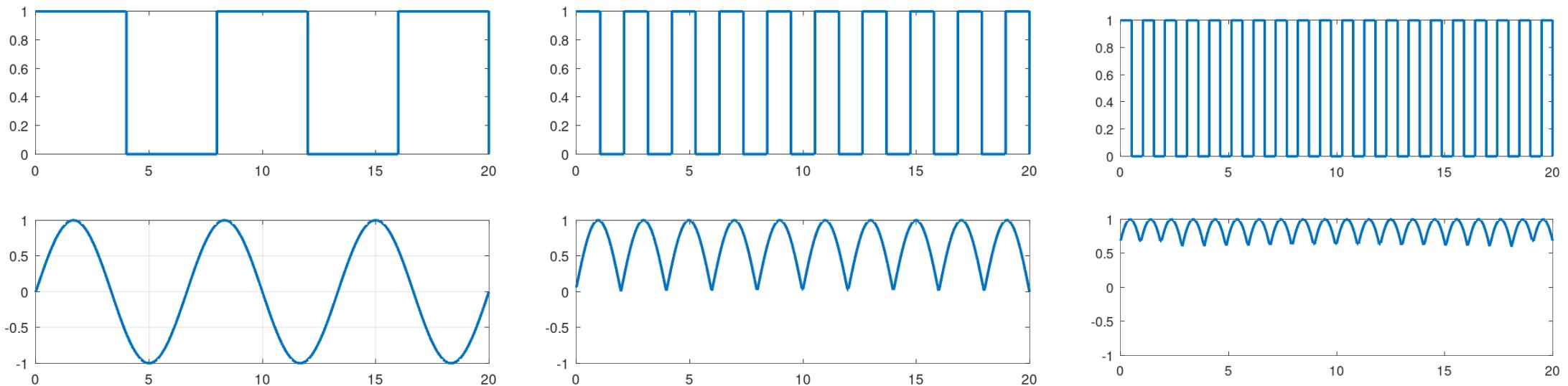
With **higher** frequencies -> harder for Photodiodes to detect



Missed Opportunity: Light has more Properties

Direct Detection Transceiver limits

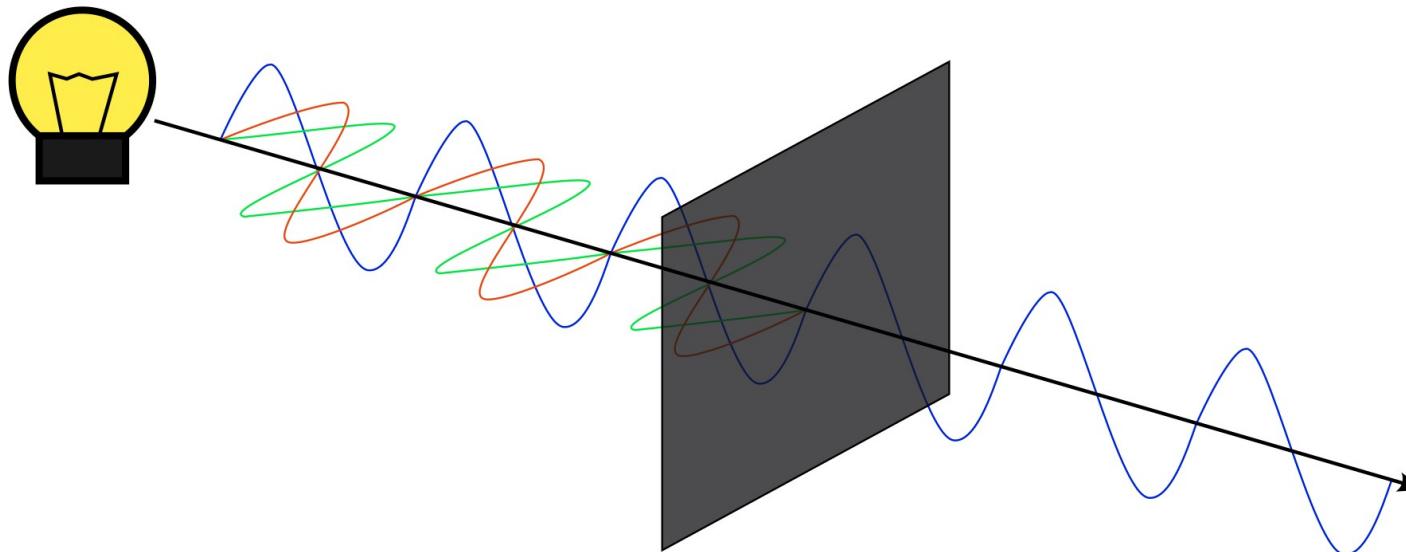
With **higher** frequencies -> harder for Photodiodes to detect



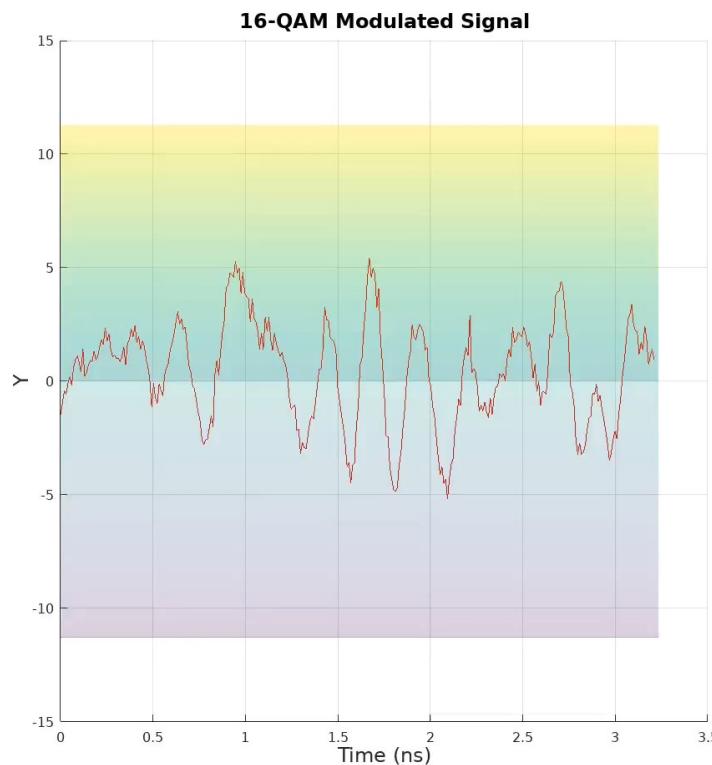
Missed Opportunity: Light has more Properties

Main Properties of Photonic Waves

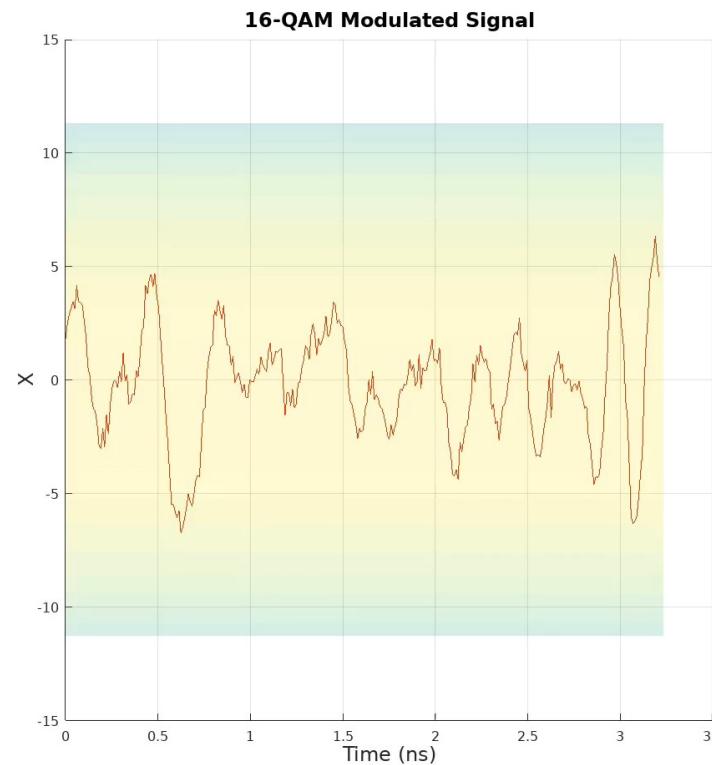
- Besides **Amplitude**, also **Phase** and **Polarisation**
- More properties per Carrier = Higher Bandwidth



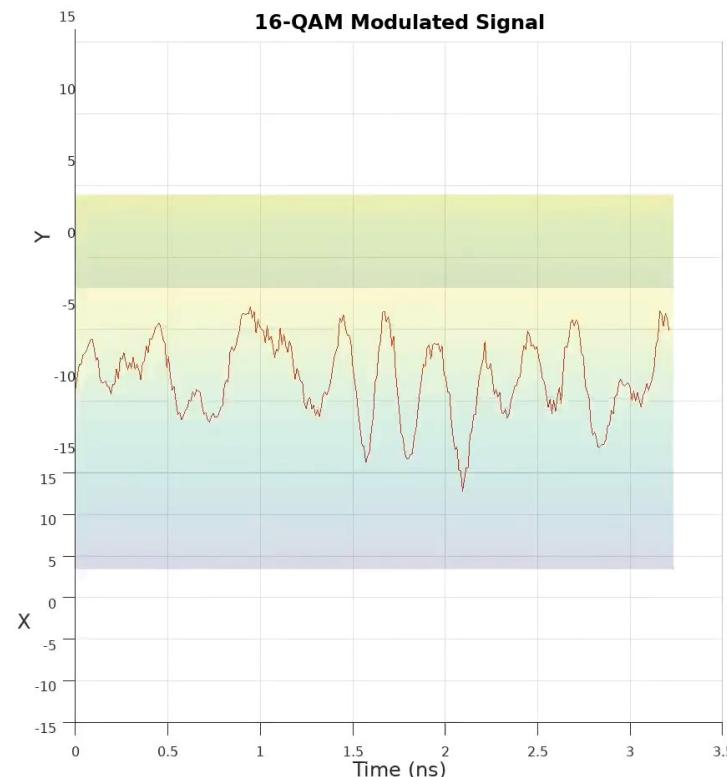
Polarisation Signal on X and Y Plane



Polarisation Signal on X and Y Plane



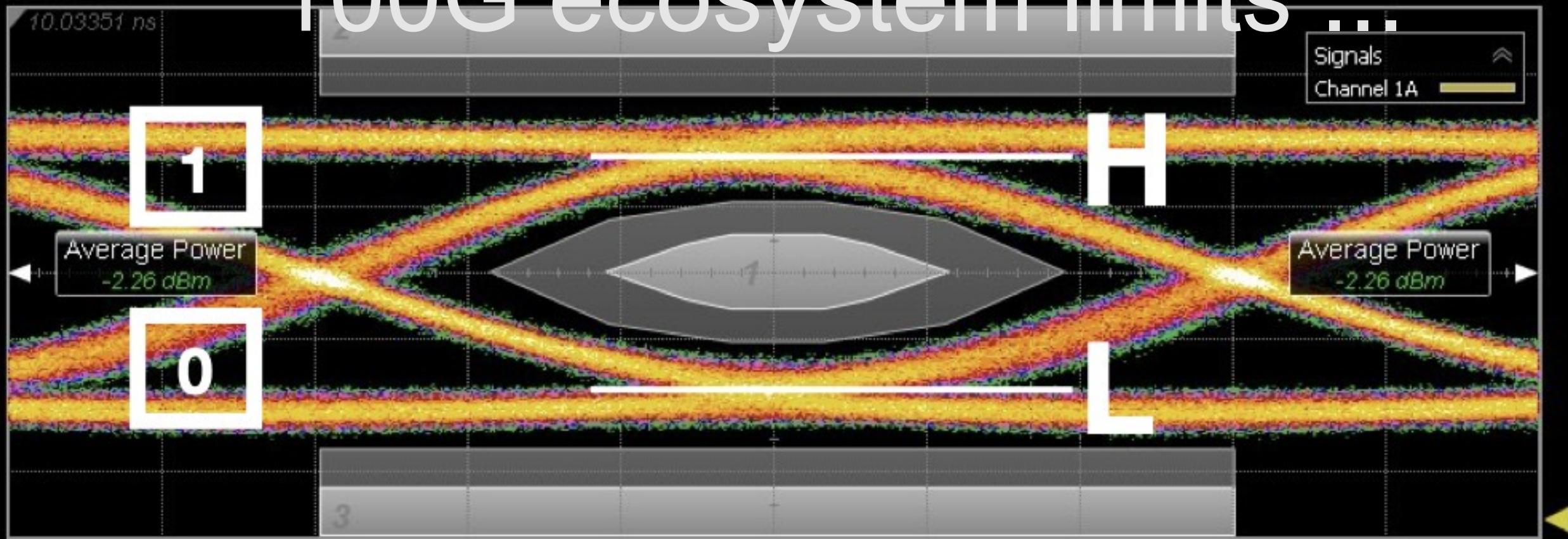
Polarisation Signal on X and Y Plane



Waveform

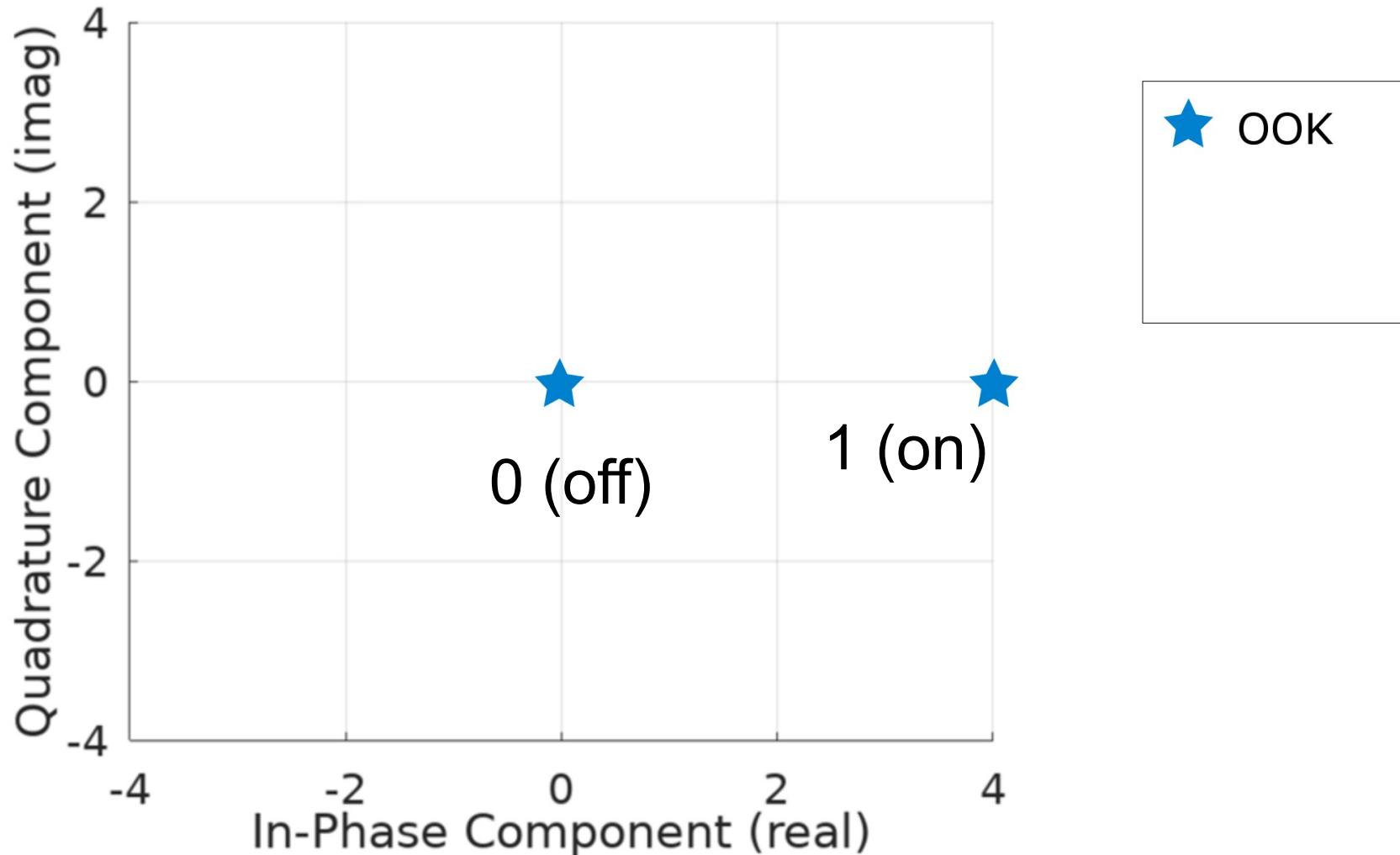


100G ecosystem limits ...

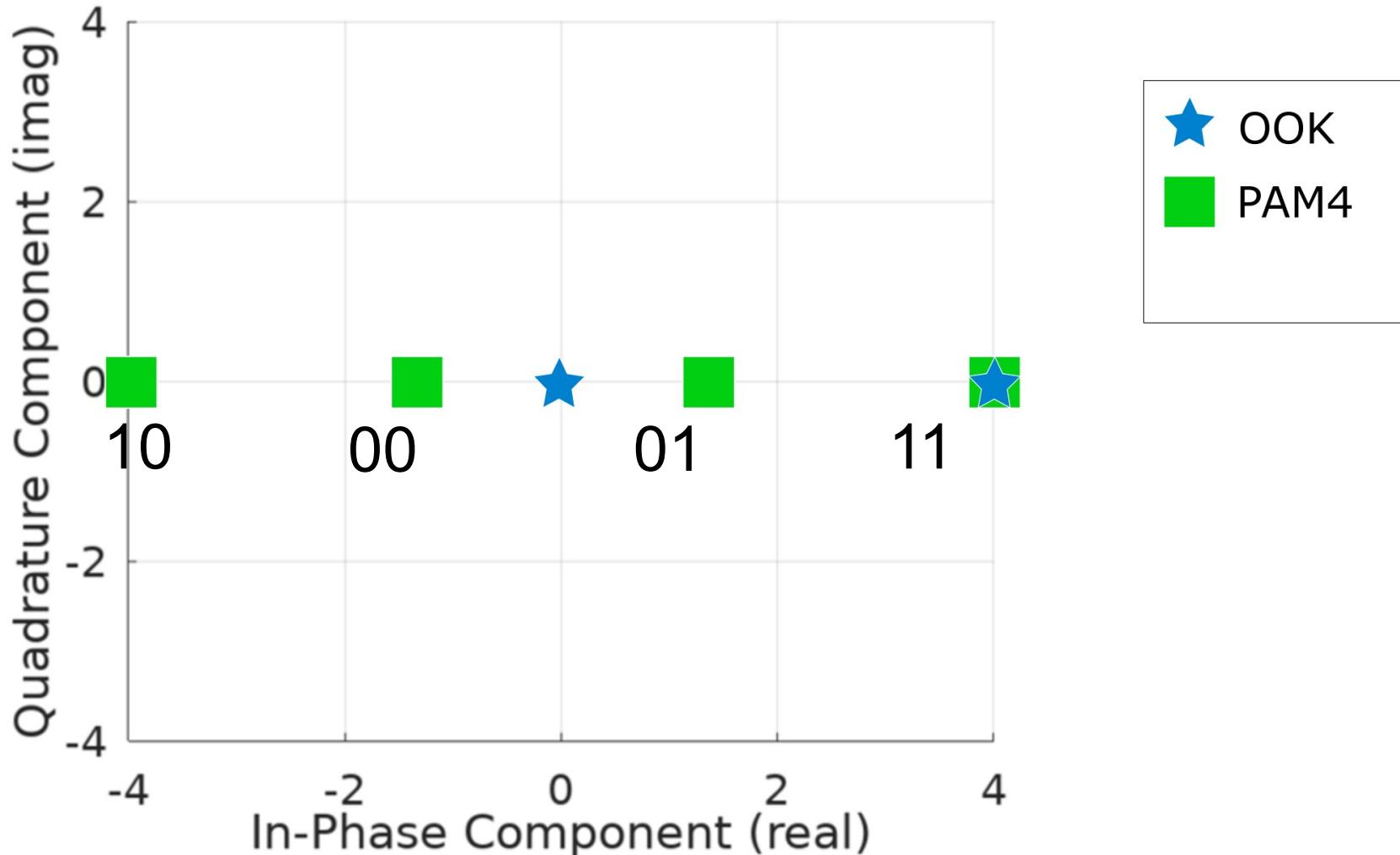


eye diagram does not cover phase

Constellation Diagramm

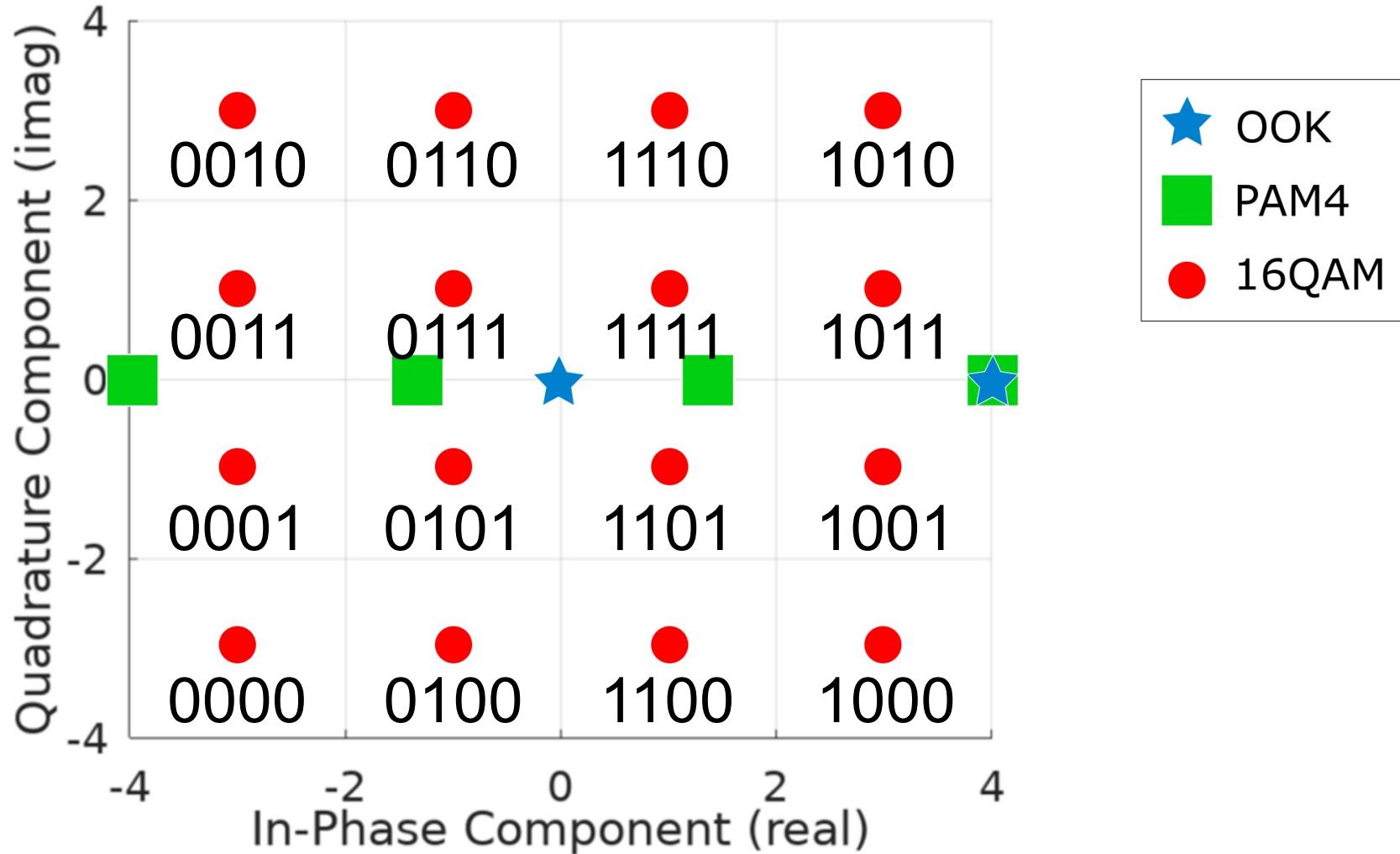


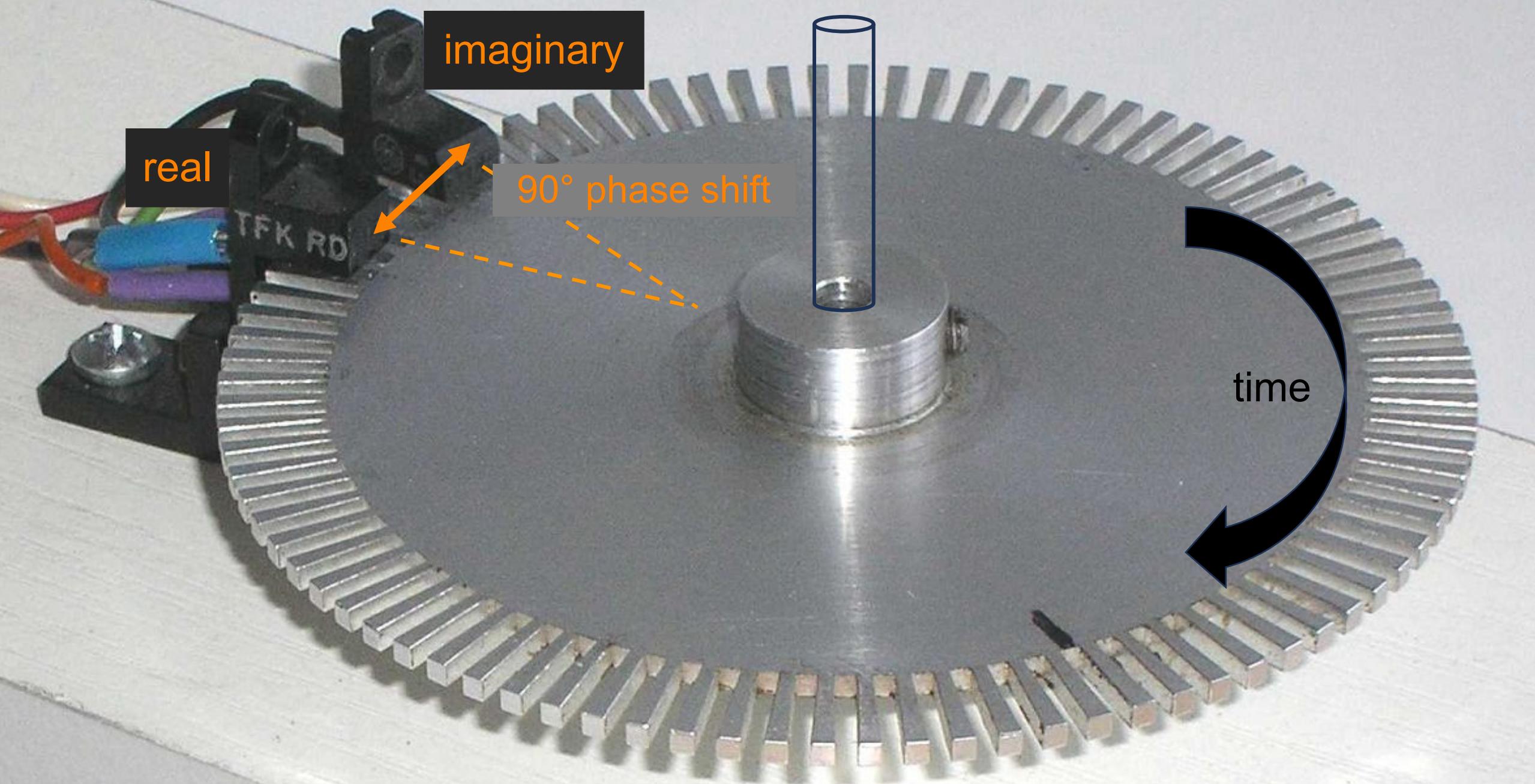
Constellation Diagramm



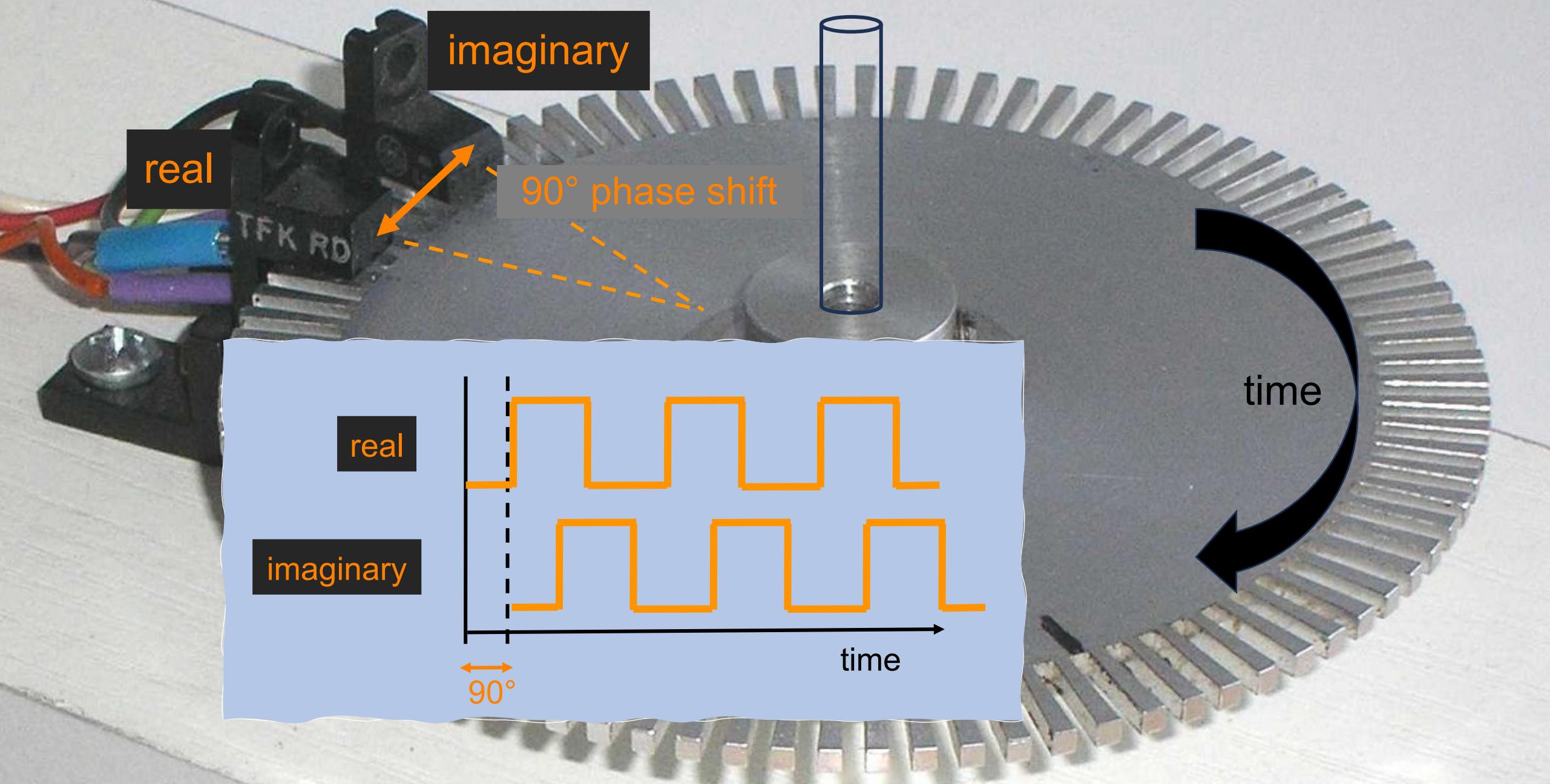
Constellation Diagramm

90°
phase
shifted
amplitude





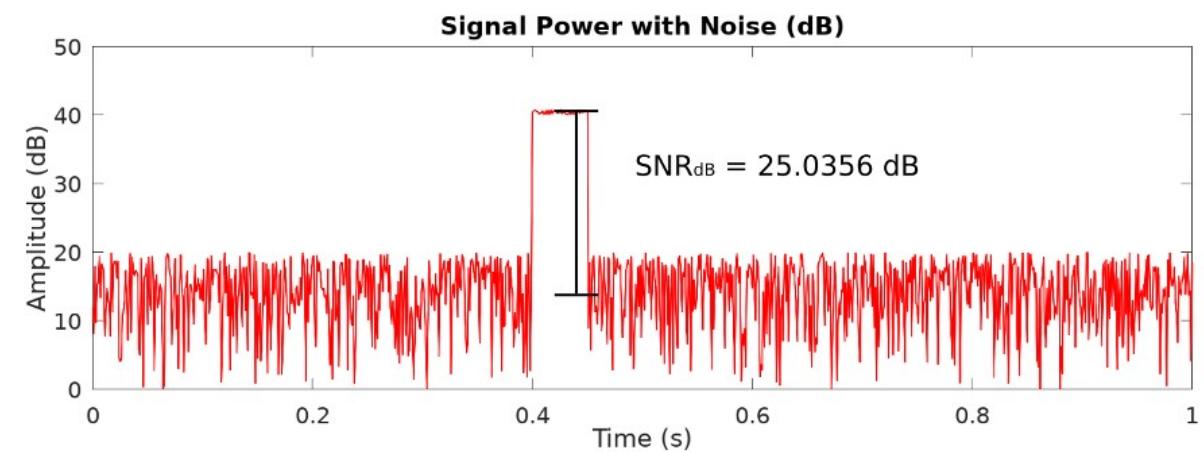
source: [9]



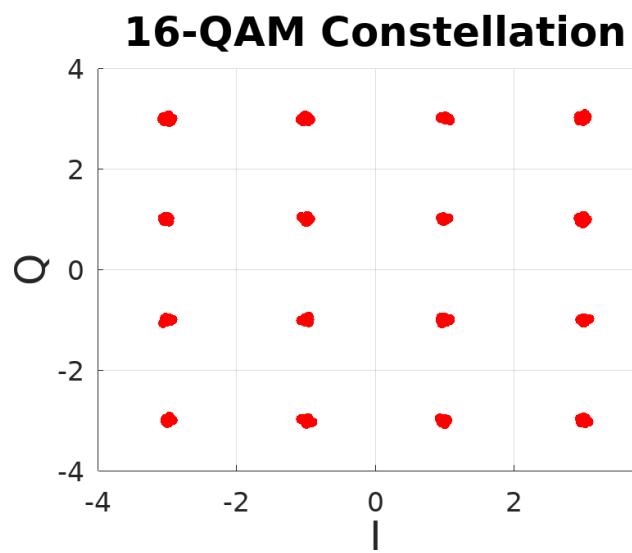
source: [9]

Measuring Signal Quality

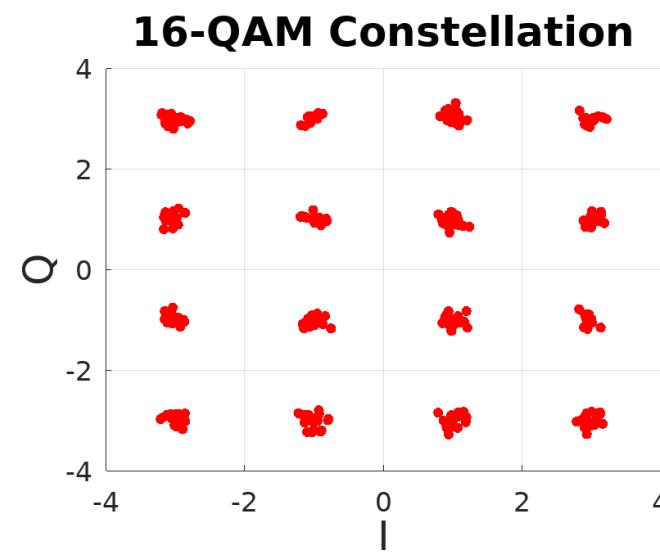
- **SNR** = Signal-to-Noise-Ratio
- Convenience of using decibels for **small** and **large** values
- (e)SNR vs OSNR:
electrical vs **optical**



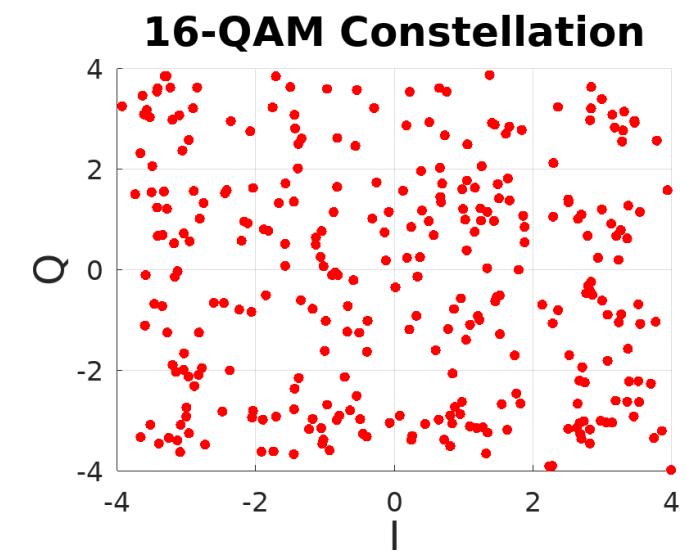
Phase and Amplitude Errors



SNR = 30 dB



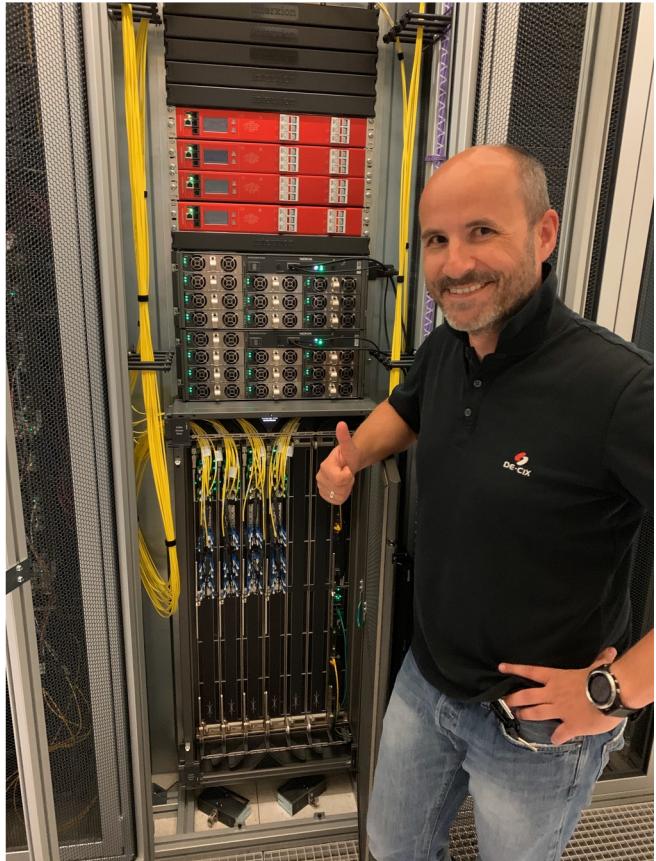
SNR = 20 dB



SNR = 5 dB

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>

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                      DCO          : Enabled
Model Number       : 3HE16564AARA01 NOK INUIAPHAA
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
...
```

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
-----
```

analysis with the CLI

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

```
...
```

```
=====
Transceiver Digital Diagnostic Monitori
=====
```

```
Value Hig
```

```
Temperature (C) +48.0
```

```
Supply Voltage (V) 3.26
```

```
=====
Transceiver Lane Digital Diagnostic Mon
```

```
High A
```

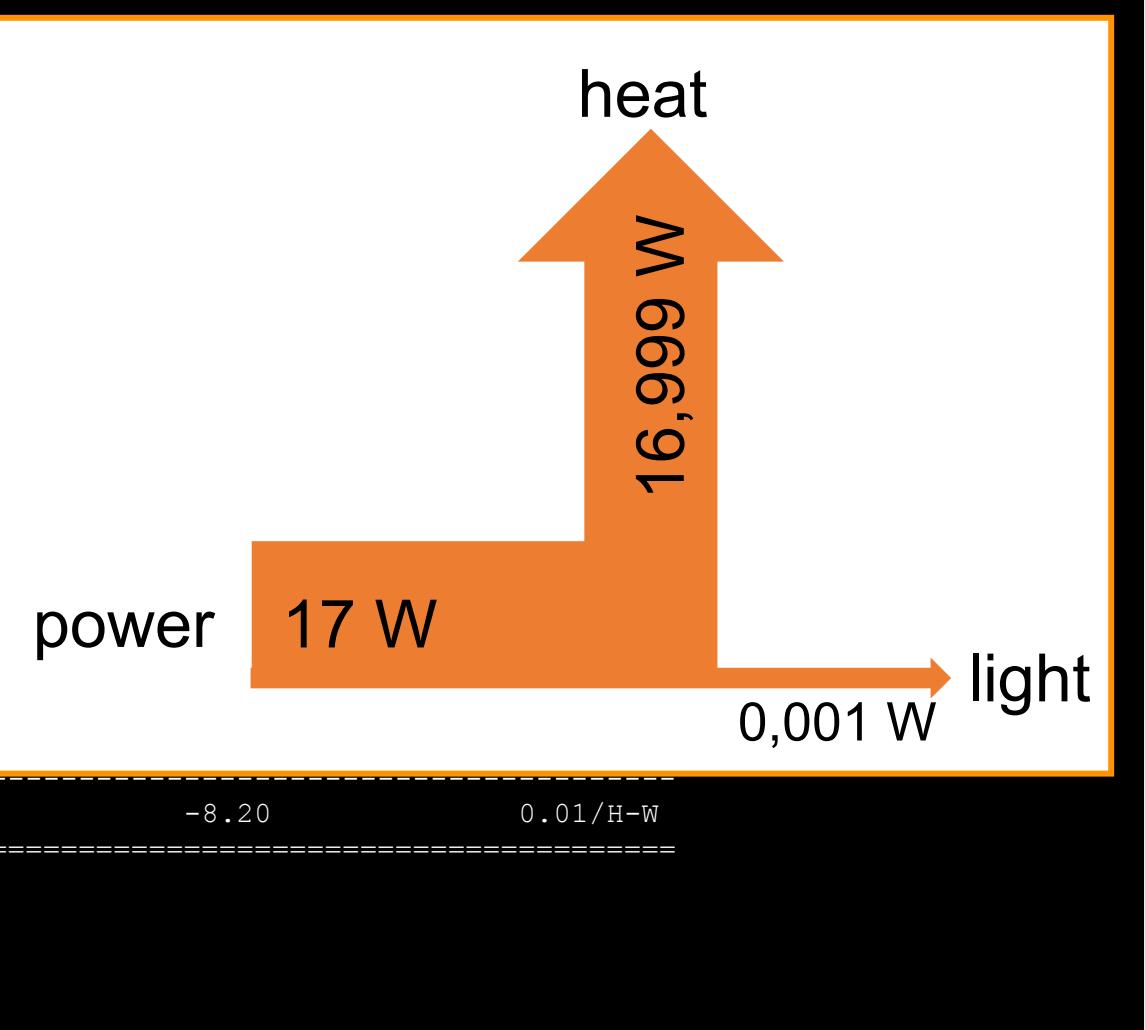
```
Lane Tx Output Power (dBm)
```

```
Lane Rx Optical Pwr (avg dBm)
```

```
=====
Lane ID Temp(C) /Alm Tx Bias(mA) /A
```

```
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)

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, 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
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
=====
```

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
```

```
=====
```

Signal-to-Noise Ratio (SNR)

```
still show port 8/1/c7, almost done  
...  
=====  
Coherent Optical Module  
=====  
Cfg Tx Target Power: 1.00 dBm Pres  
Cfg Rx LOS Thresh : -23.00 dBm Cfg  
  
Disp Control Mode : automatic Swee  
Cfg Dispersion : 0 ps/nm Swee  
CPR Window Size : 32 symbols Rx I  
Compatibility : openZrpOfec1  
Cfg Tx Power Min : -22.90 dBm Cfg  
  
Cfg Alarms : modflt mod netrx nettx hosttx  
Alarm Status :  
Defect Points :  
  
Rx Q Margin : 2.4 dB  
OSNR X Polar: 34.4 dB  
OSNR Y Polar: 34.4 dB  
  
Module State : ready  
Tx Turn-Up States : init laserTurnUp laserReadyOff laserReady  
modulatorConverge outputPowerAdjust  
Rx Turn-Up States : init laserReady waitForInput adcSignal opticalLock  
demodLock
```

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

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	aui2	2x 100GAUI-2 (2x 50G)	oFEC	DP-QPSK	60.1GBd
				c2-100g-aui2	2x 100GAUI-2 (2x 50G)	oFEC	DP-QPSK	60.1GBd
				c1-100g-aui2	2x 100GAUI-2 (2x 50G)	oFEC	DP-QPSK	60.1GBd
10	OpenZR+ MSA	openZrpOfec2	1x 100GBASE-R	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

Compatibility / Application Mode

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

```
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
```

```
...
```

```
3x 100GBASE-R c3-100g
```

```
3x 100GAUI-2 (2x 50G)
```

```
oFEC DP-8QAM
```

```
60.1GBd
```

```
4x 100GBASE-R c4-100g
```

```
4x 100GAUI-2 (2x 50G)
```

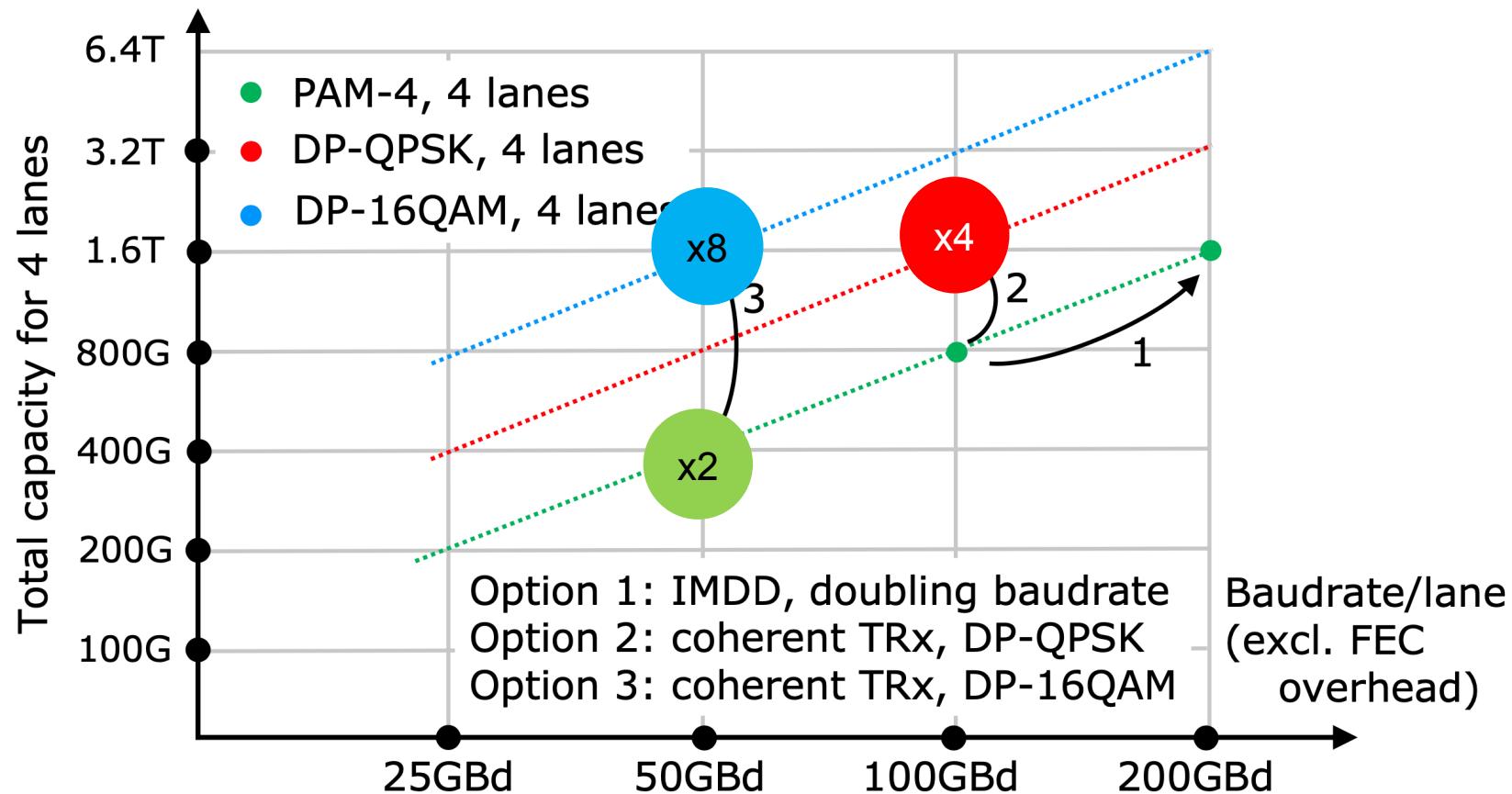
```
CFEC DP-16QAM
```

```
59.8GBd
```

OIF 400ZR vs. OpenZR+ MSA optical parameters

	OIF 400ZR	OpenZR+ MSA	
		60LA	60HA
<i>max. TX power</i>	-6 dBm	-10 dbm	0 dBm
<i>min. RX power</i>	-12 dBm	-12 dBm	-12 dBm
<i>CD Tolerance</i>	2,400 ps/nm	20,000 ps/nm	
<i>PMD Tolerance</i>	10 ps	20 ps	
<i>OSNR Tolerance</i>	26 dB	24 dB	

more bandwidth for 800G, 1.6T or 3.2T with coherent



source: [1]

Want to learn for yourself?

Your switch gear
+ our coherent optics
= **less hickups, more knowhow**



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-zrzsqsfp-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, OIForum; 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
9. Rotary optical encoder model, <https://commons.wikimedia.org/wiki/File:Encoder.jpg> by Rrudzik (accessed Mar. 2024)