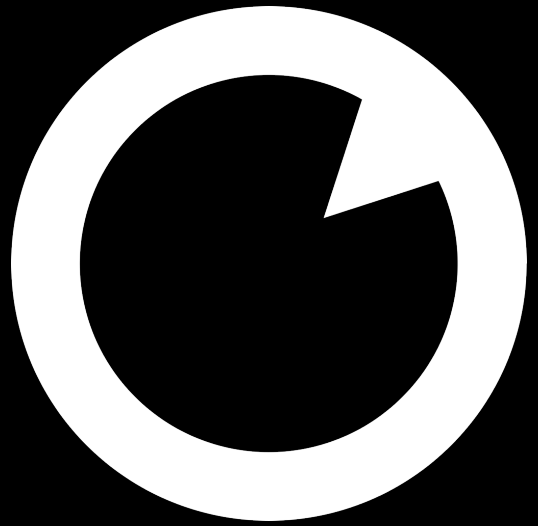
coherent optical transceivers



current capabilities and
future possibilities

100G ecosystem limits …

CFP

QSFP28

CFP2

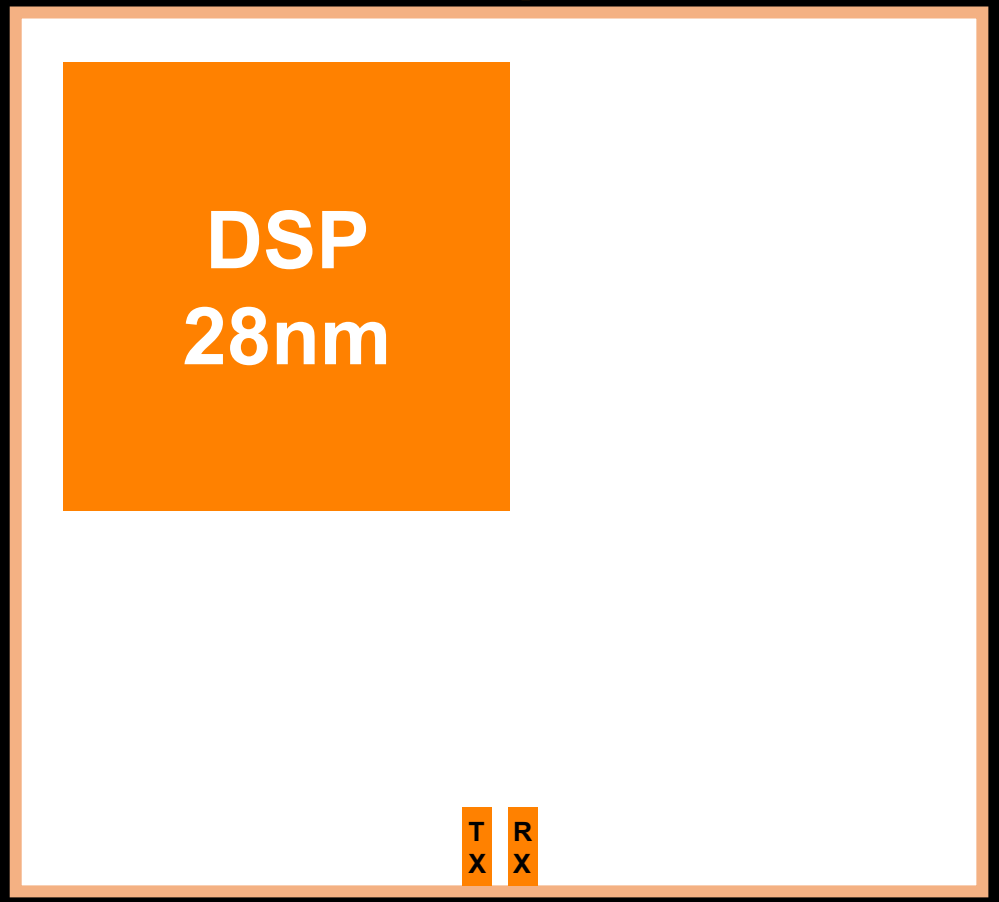
CFP4

CPAK

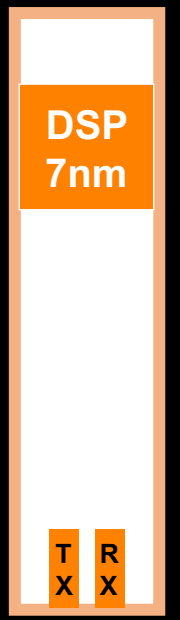
- ratio of **power consumption** to formfactor
- focus on **inner datacenter links**
- **variation** of diverse hardware

… sorted now with 400G

DWDM transponder card

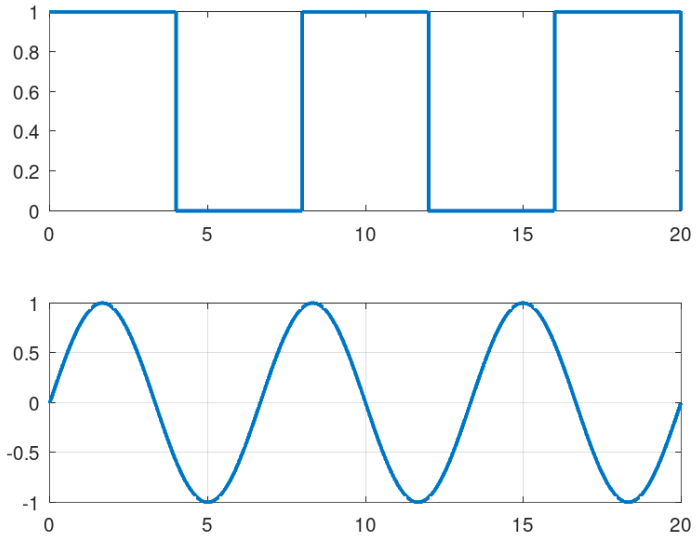


pluggable QSFP-DD



Direct Detection Transceiver limits

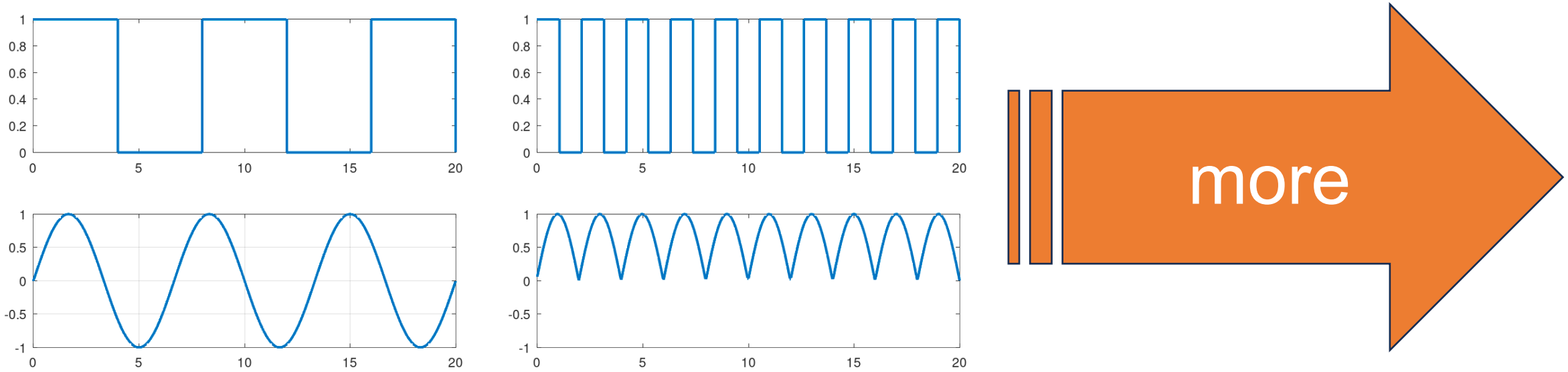
With **higher** frequencies -> harder for Photodiodes to detect



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

Direct Detection Transceiver limits

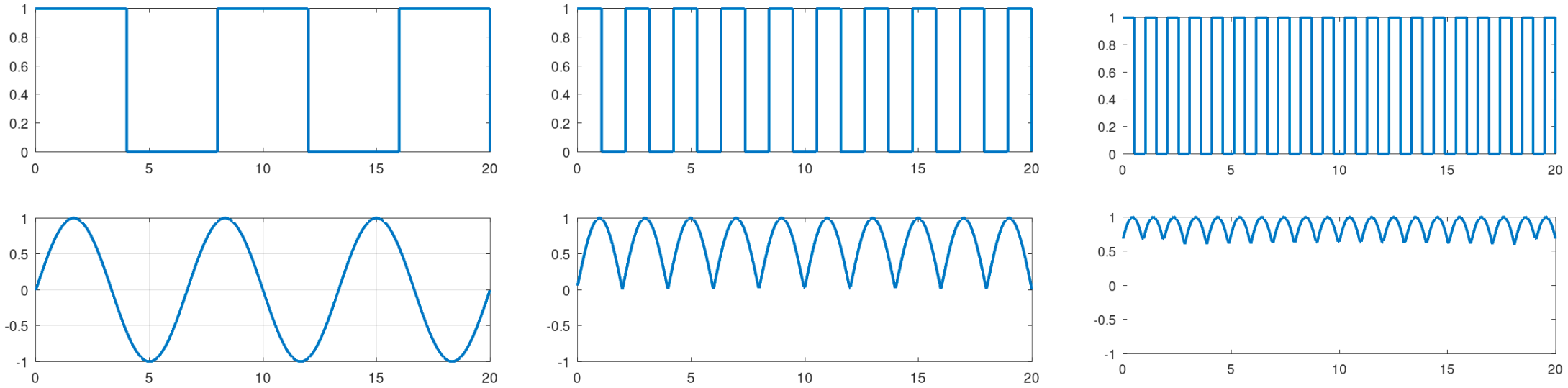
With **higher** frequencies -> harder for Photodiodes to detect



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

Direct Detection Transceiver limits

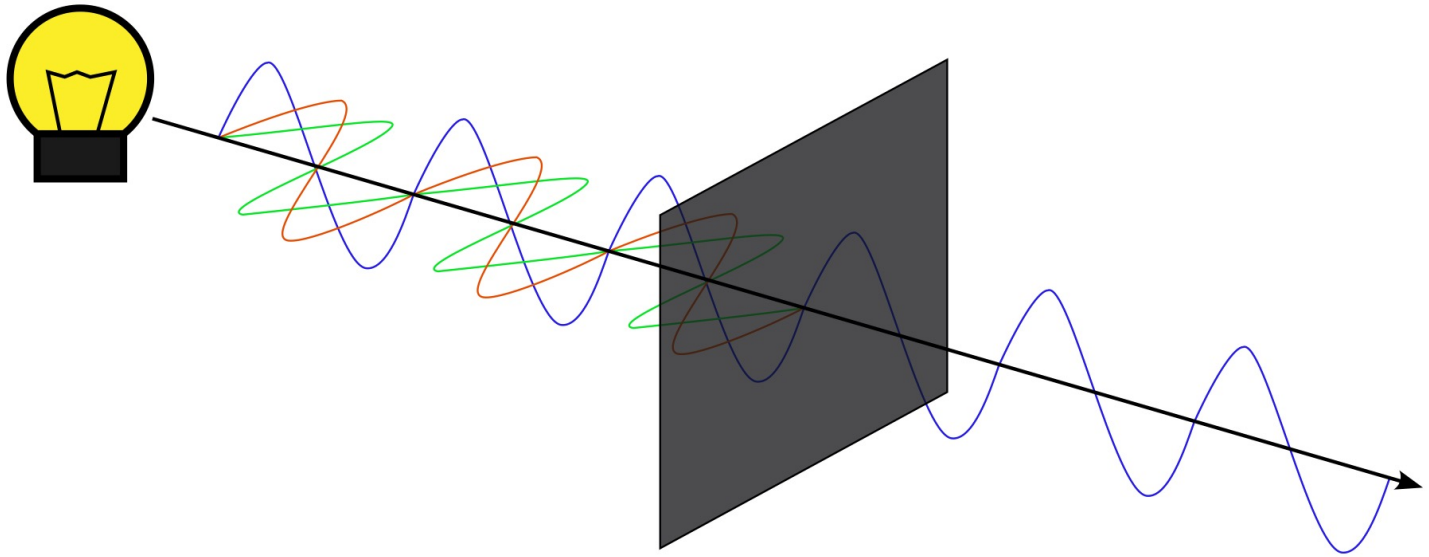
With **higher** frequencies -> harder for Photodiodes to detect



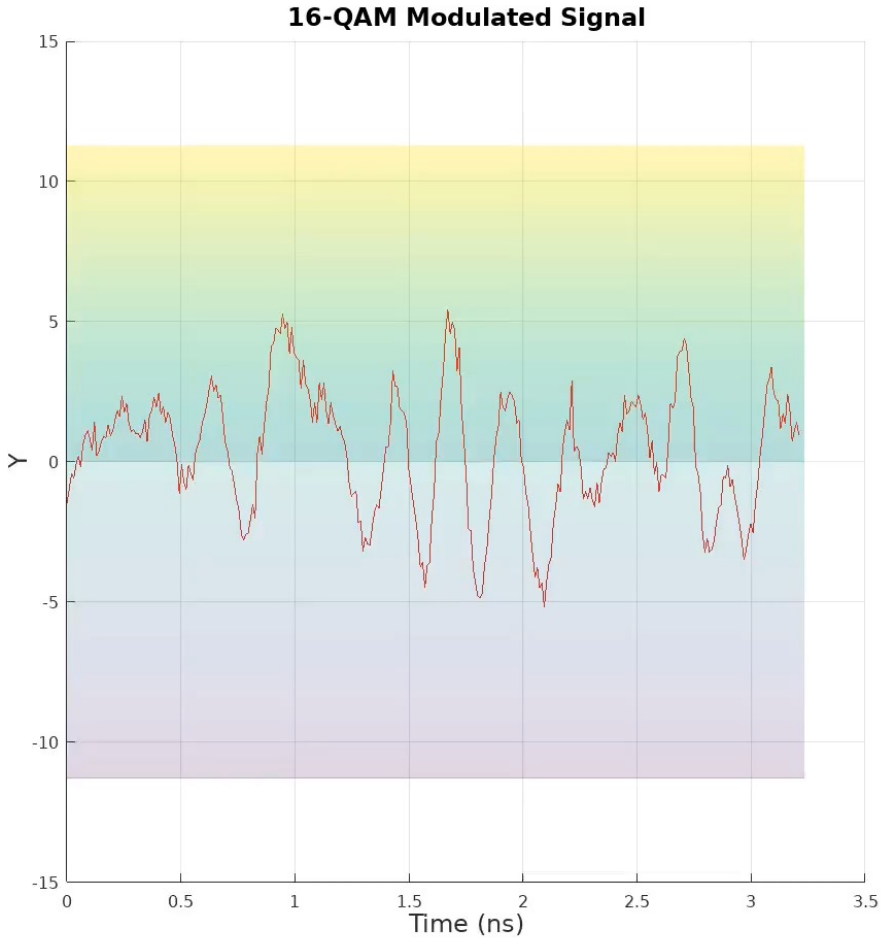
Missed Opportunity: **Light** has more **Properties**

Main Properties of Photonic Waves

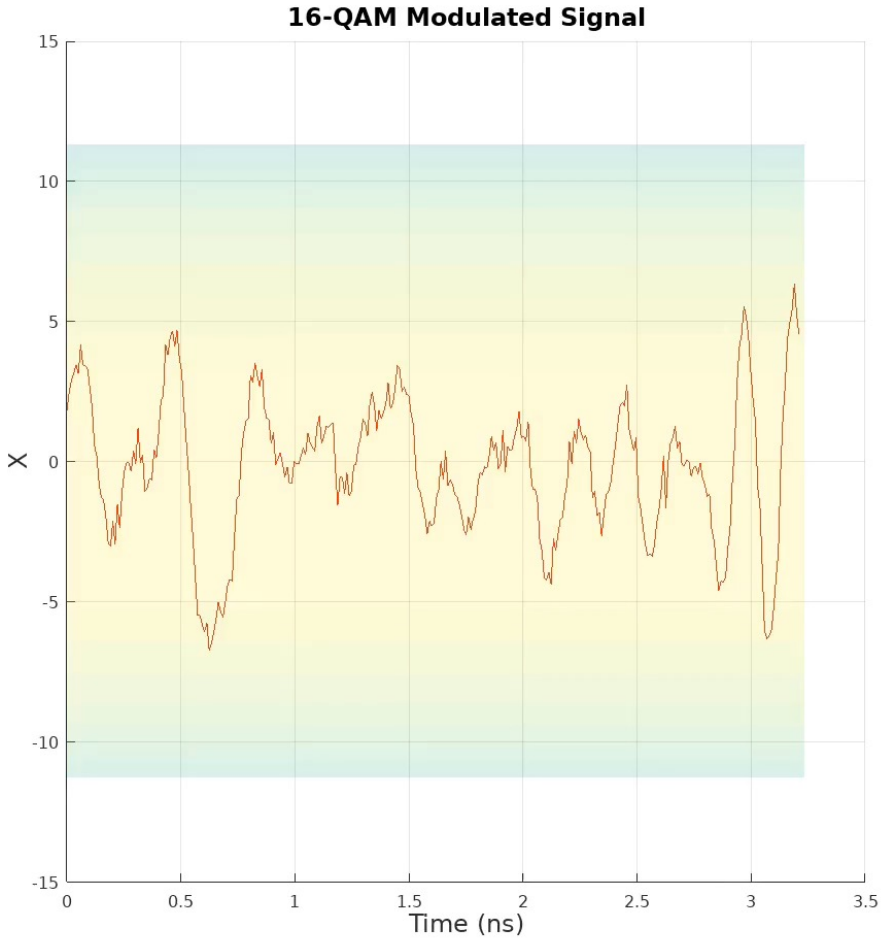
- Besides **Amplitude**, also **Phase** and **Polarisation**
- More properties per Carrier = Higher Bandwidth



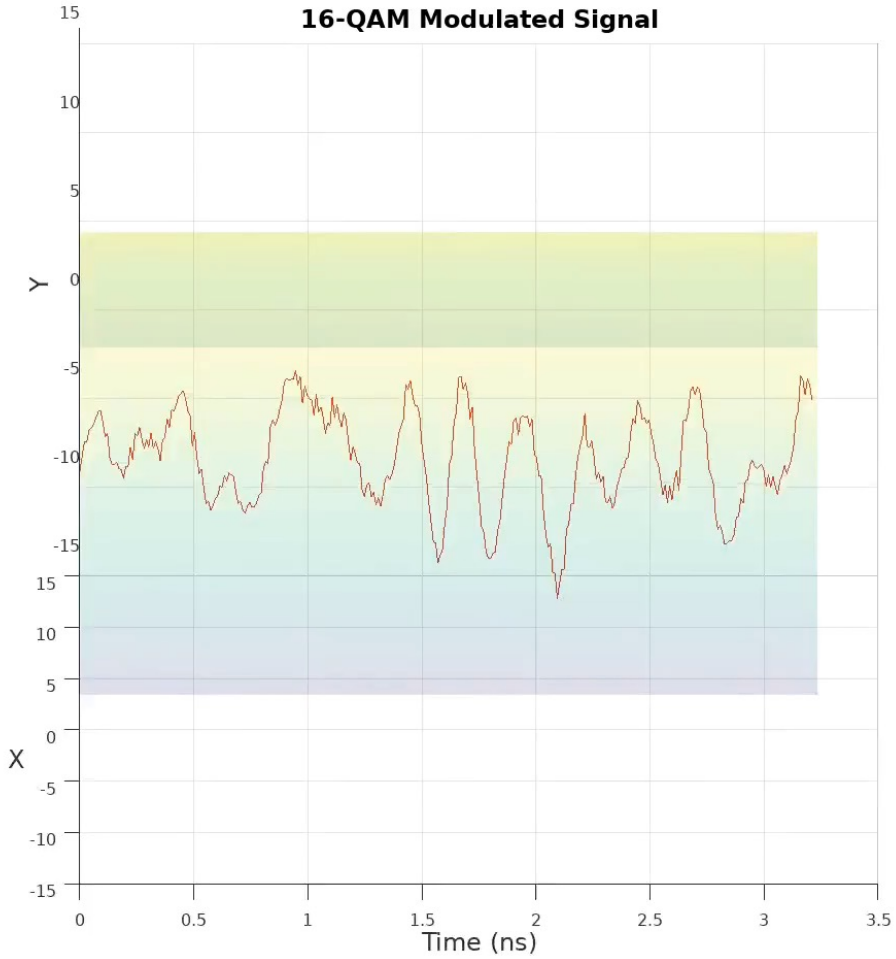
Polarisation Signal on X and Y Plane



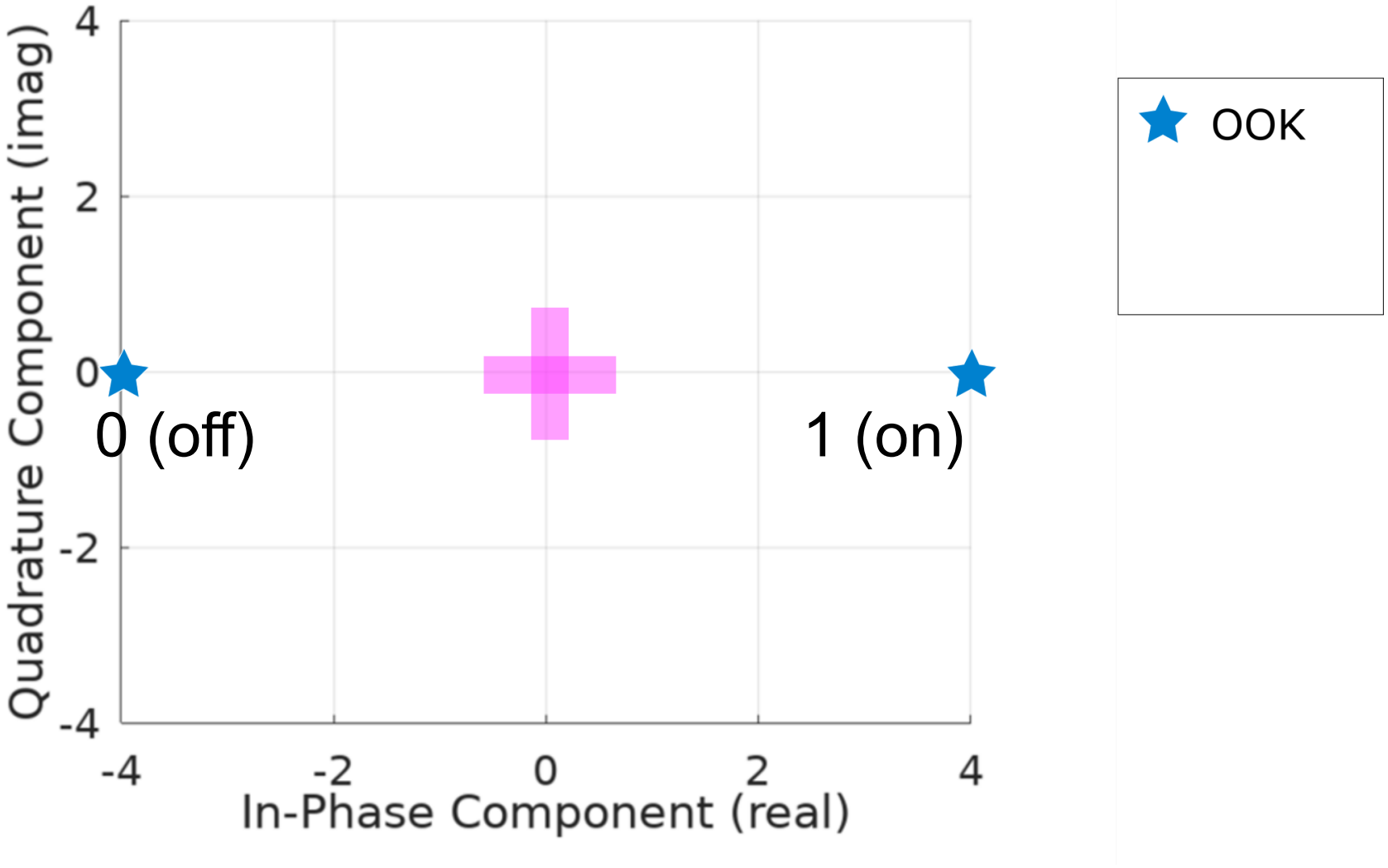
Polarisation Signal on X and Y Plane



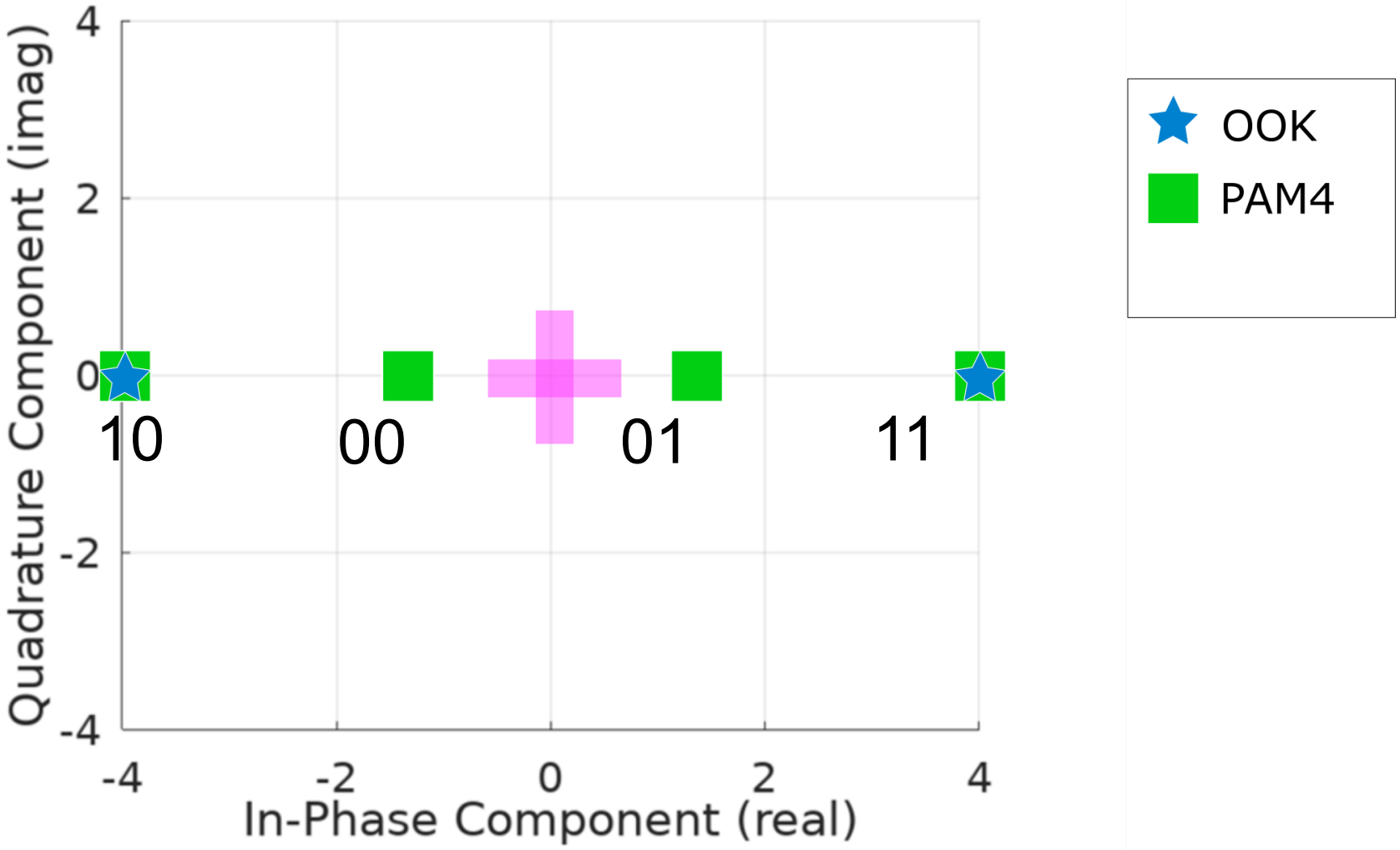
Polarisation Signal on X and Y Plane



Constellation Diagramm

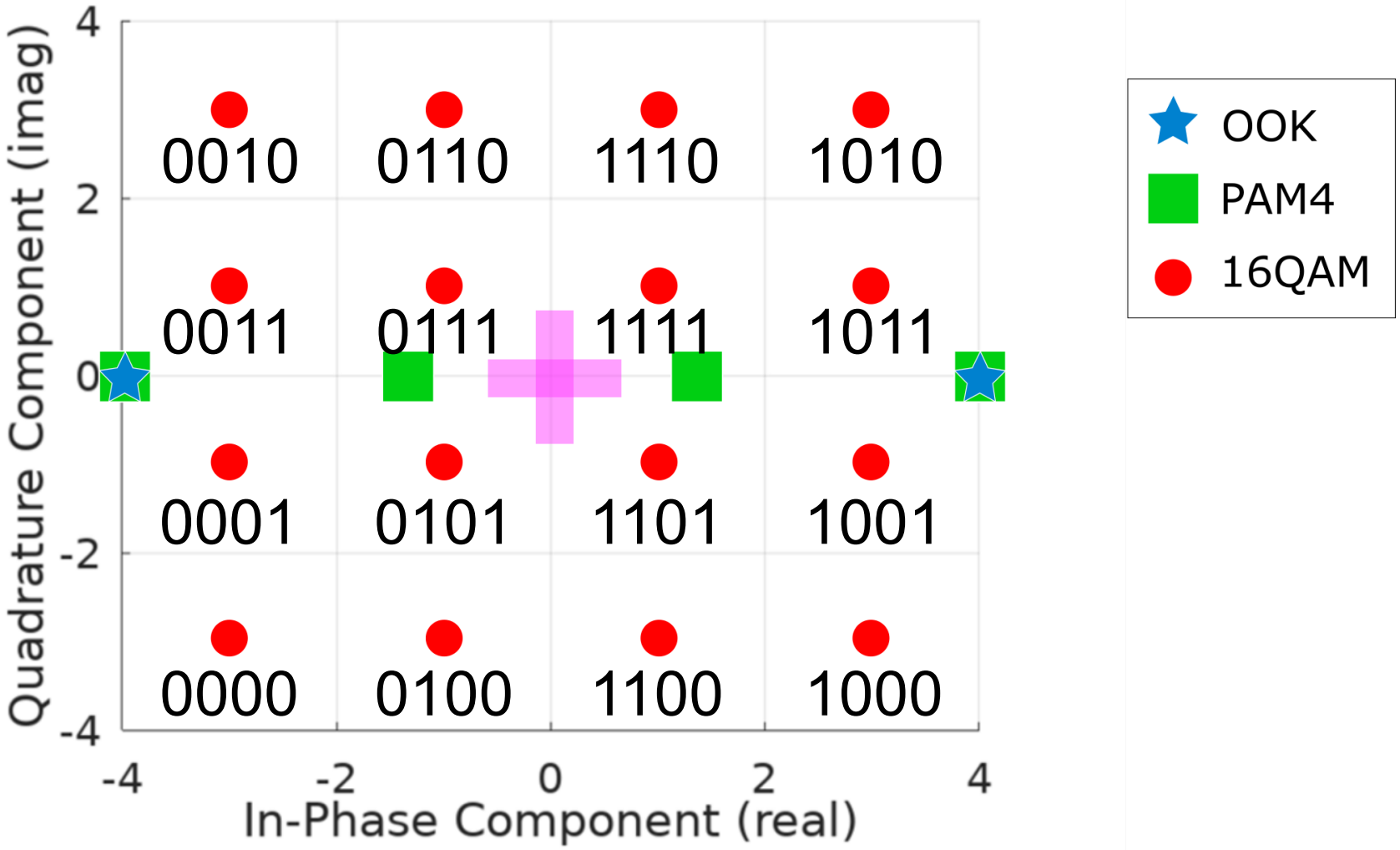


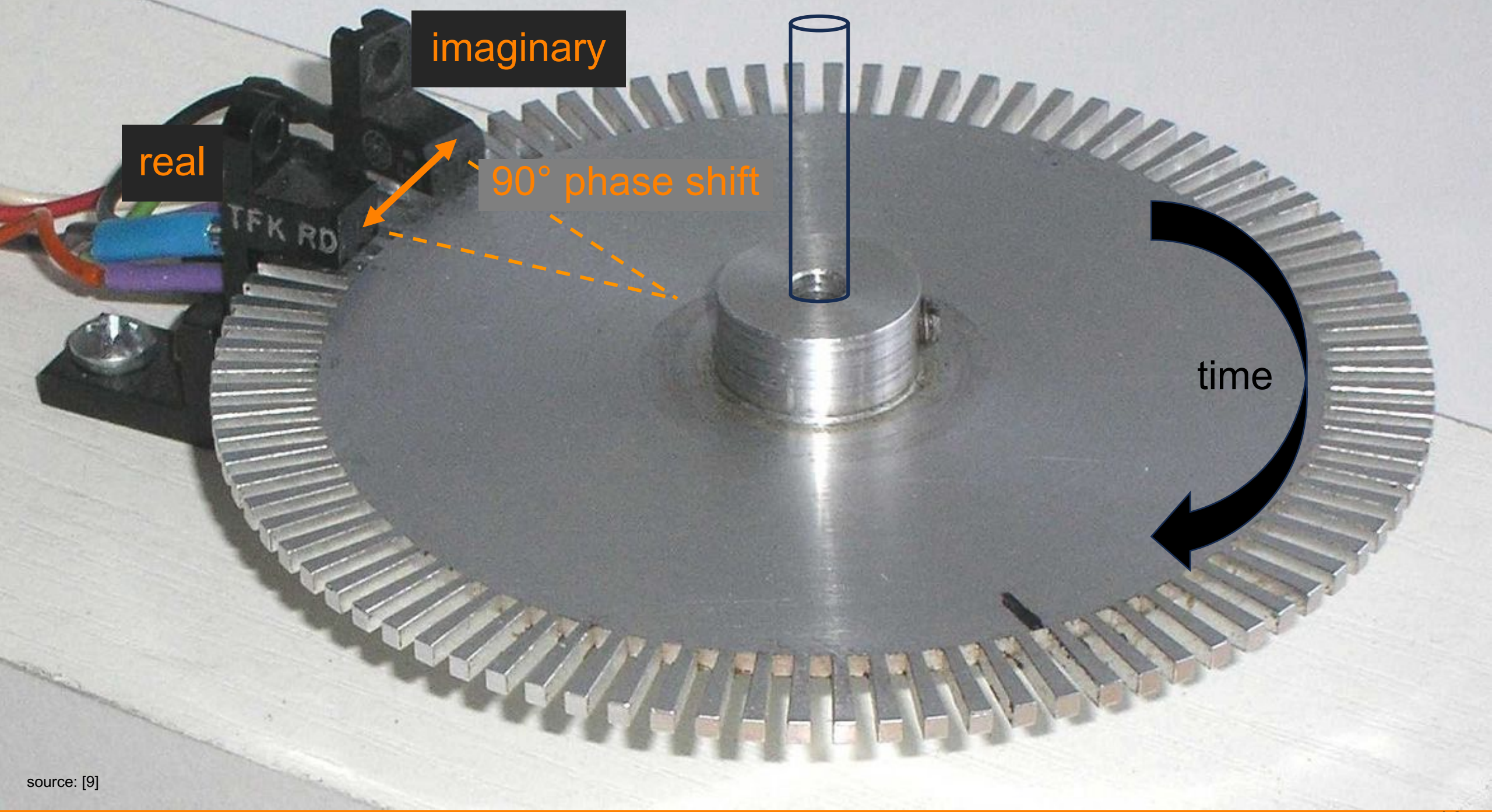
Constellation Diagramm



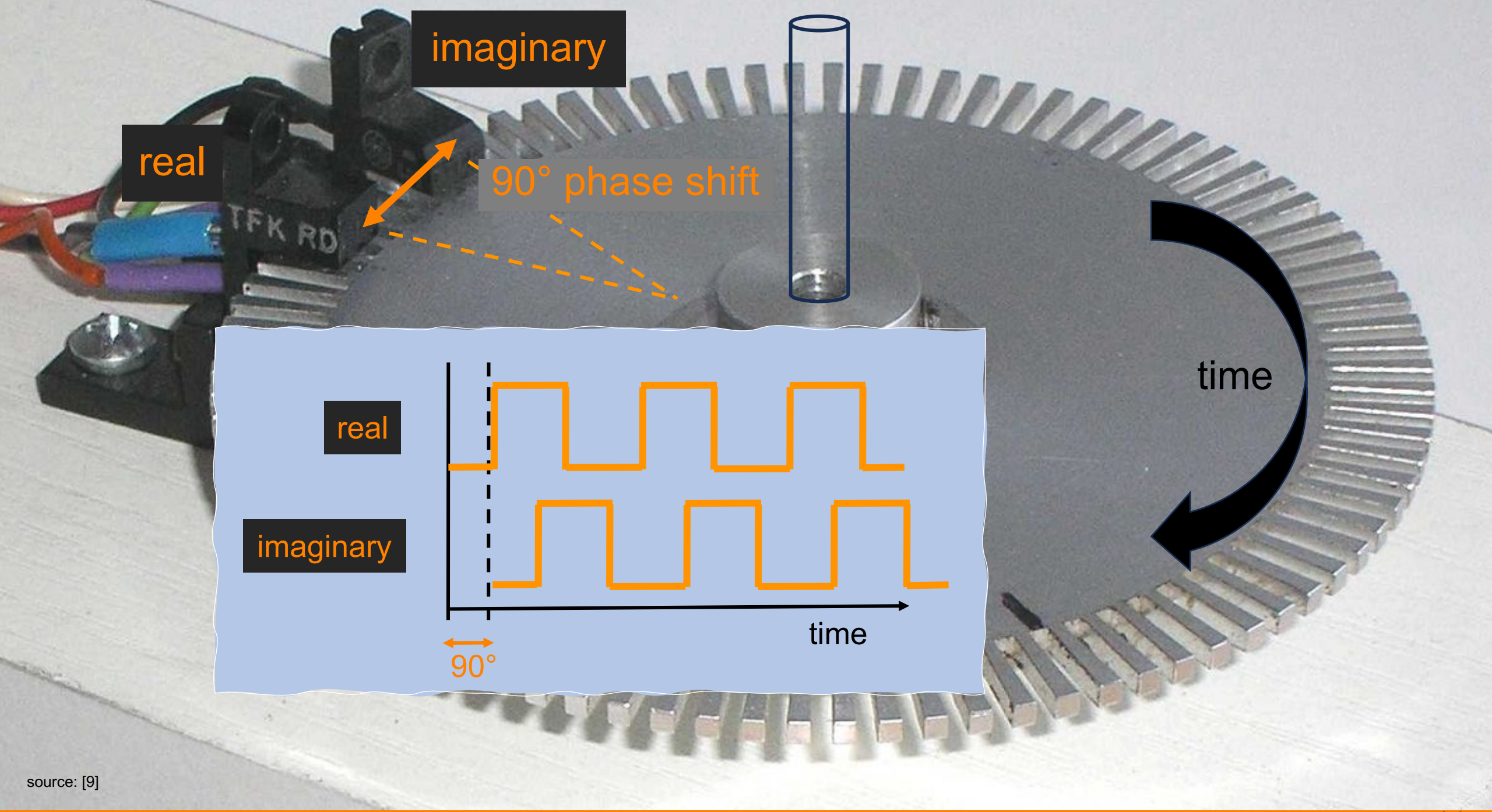
Constellation Diagramm

90° phase shifted amplitude

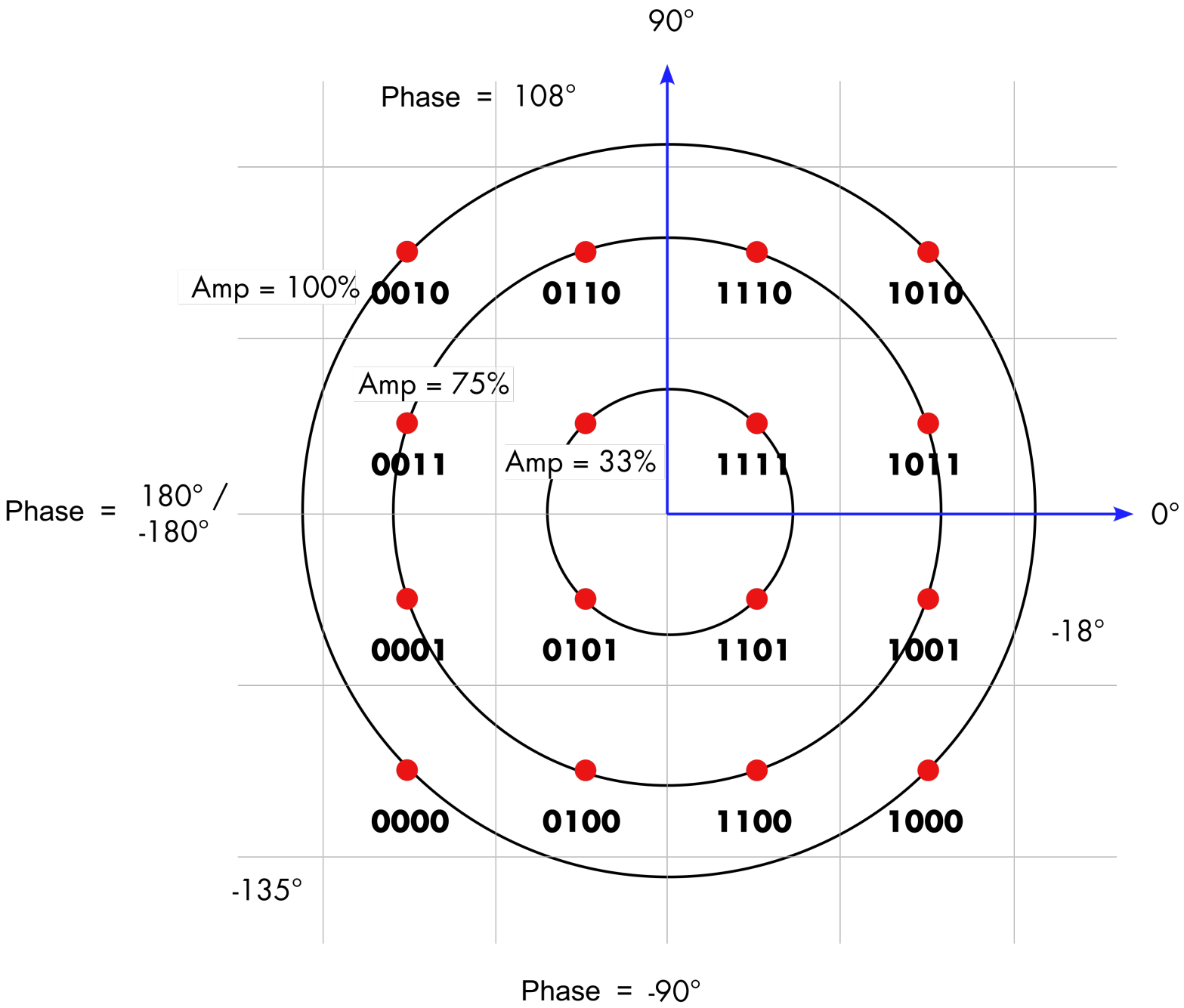


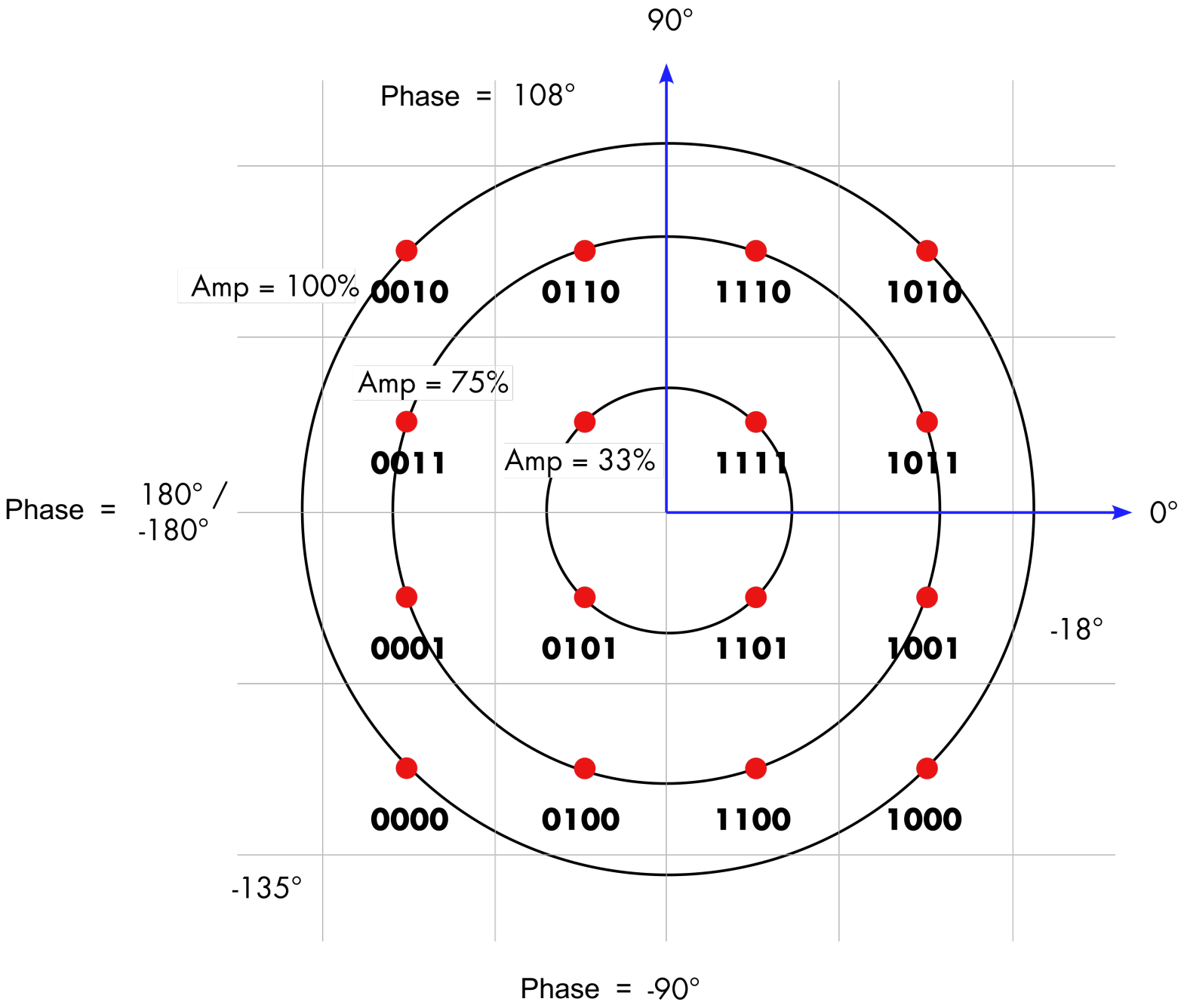


source: [9]



source: [9]


90°
Phase = 108°
Amp = 100%
0010
0110
1110
1010
Amp = 75%
0011
Amp = 33%
1111
1011
Phase = 180° / -180°
0°
0001
0101
1101
1001
-18°
0000
0100
1100
1000
-135°
Phase = -90°



Who is ?

1111

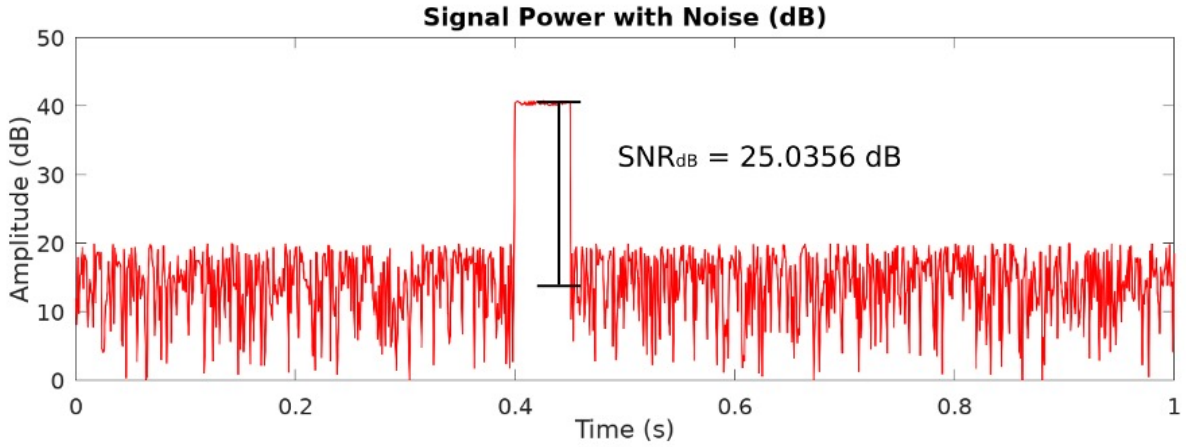
0101

0011

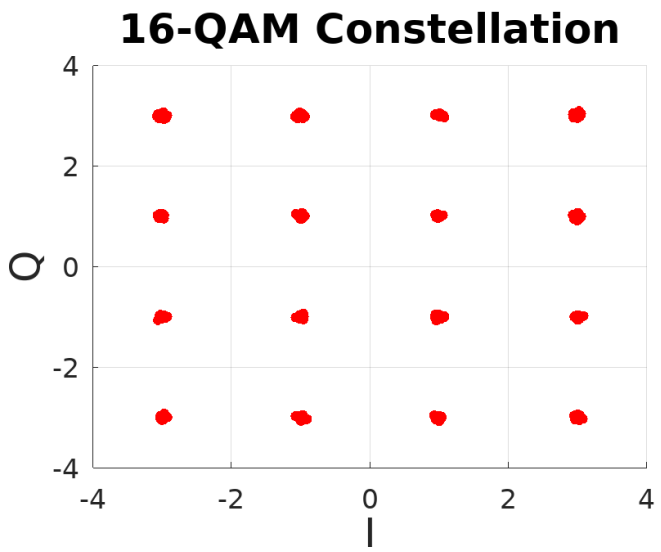
Measuring Signal Quality

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

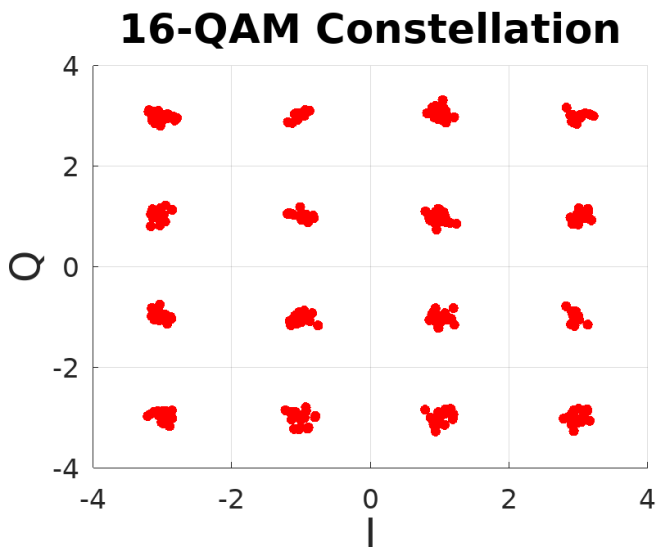
  electrical vs **optical**



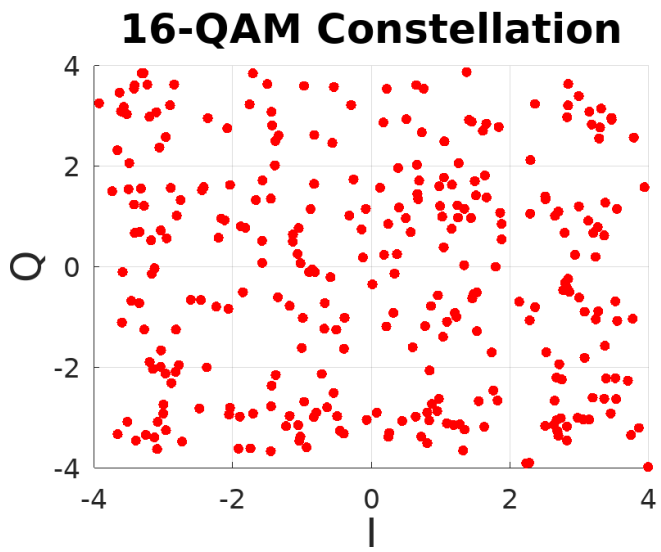
Phase and Amplitude Errors



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

DE CIX

source:Daniel Melzer; DE-CIX

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

config with the CLI

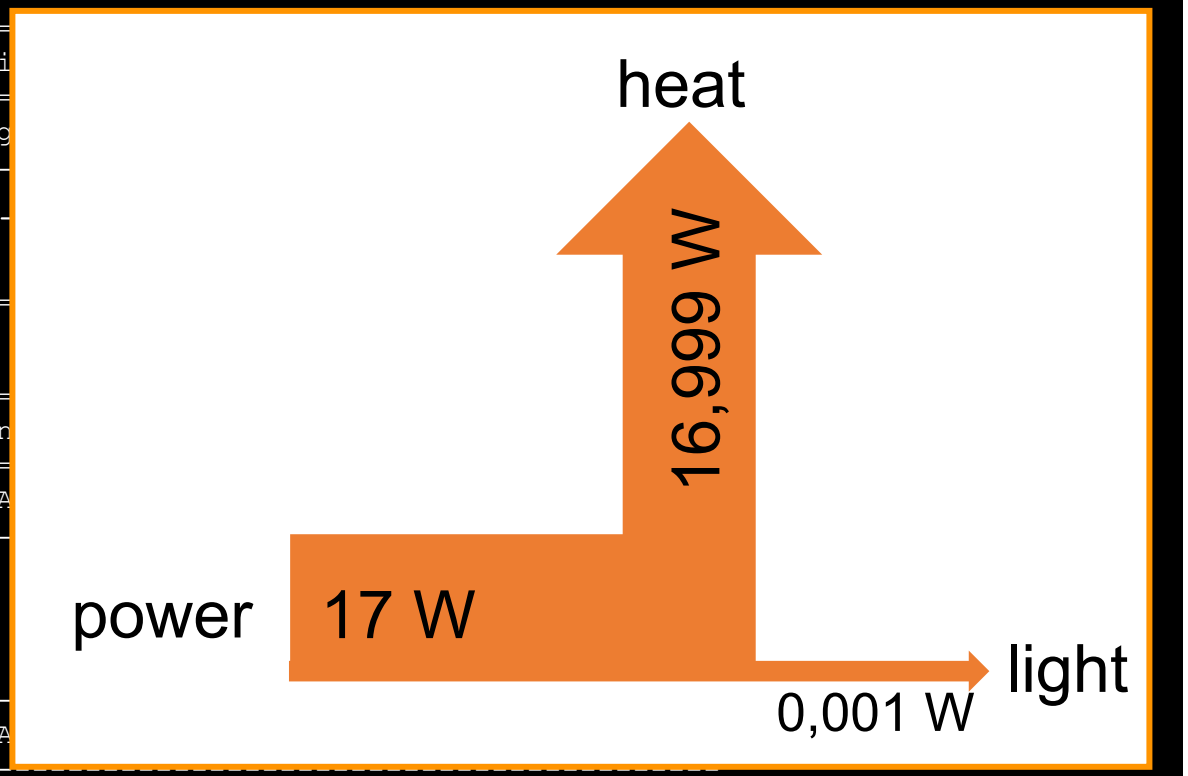
```
Nokia 7950 XRS# show port 8/1/c7

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

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                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
                                             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)

Polarisation Mode Dispersion (PMD)

```
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

                                        ====================================
```

Difference in propagation time for X and Y polarisation

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 hostt
Alarm Status        :
Defect Points       :

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

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

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-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, !??

...

===============================================================================
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: openZ
Cfg Tx Power Min   : -22.90 dBm
```

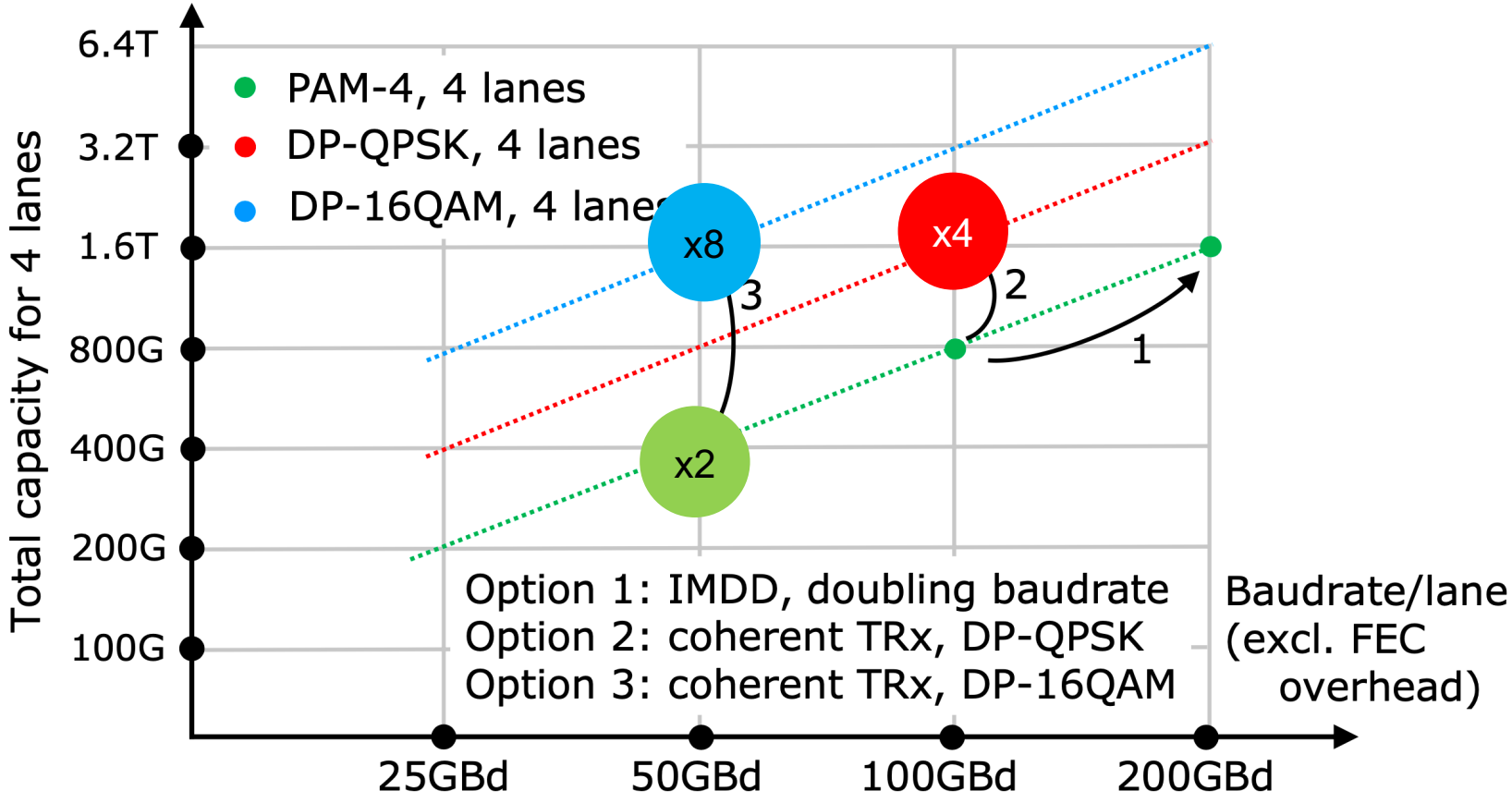
```
Nokia 7950 XRS# show port 8/1/c7

===============================================
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	enZrpOfec1					
6	OpenZR+ MSA, Enhanced	ZrpOfec2					
7	OpenZR+ MSA, Enhanced						
8	OpenZR+ MSA, Enhanced	c2					
9	OpenZR+ MSA						
10	OpenZR+ MSA						
11	OpenZR+ MSA	openZrpOfec1					
12	OpenZR+ MSA, Enhanced						
13	OIF 400ZR, amplified	oif-400g-zr					
14	OpenZR+ MSA, Enhanced	openZrpOfec2					
15	OpenZR+ MSA		100GBASE-R		1x CAUI-4 w/o FEC (4x25G)	oFEC	DP-QPSK	30.1GBd

OIF 400ZR vs. OpenZR+ MSA optical parameters

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

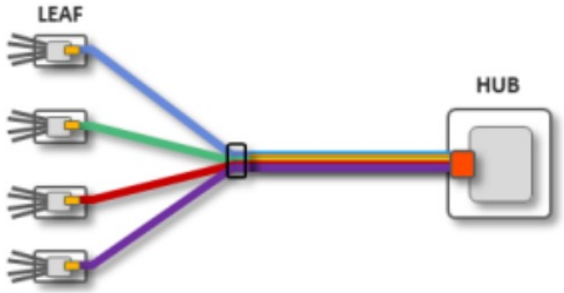
thomas.weible@flexoptix.net
gerhard.stein@flexoptix.net

Outlook: OpenXR 16 x 25Gbit/s via DSCM

Point-to-Point

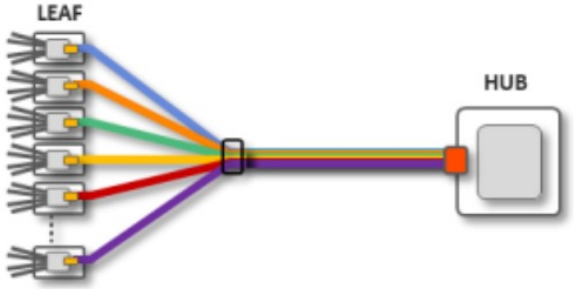
100G/200G/400G P2P

Break-out Mode



4 X 100G LEAFS TO 400G HUB

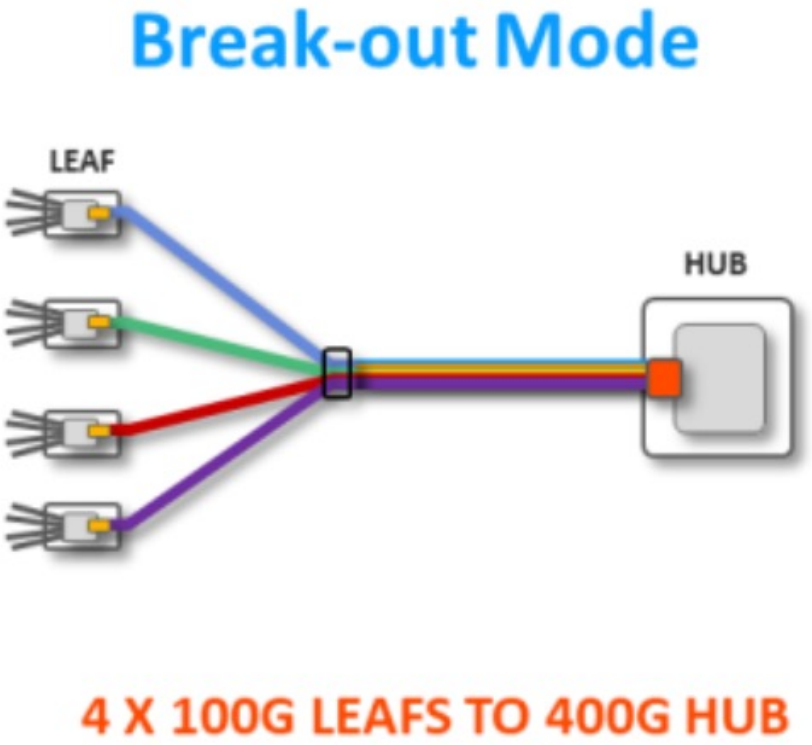
Flexible Point-to-Multipoint



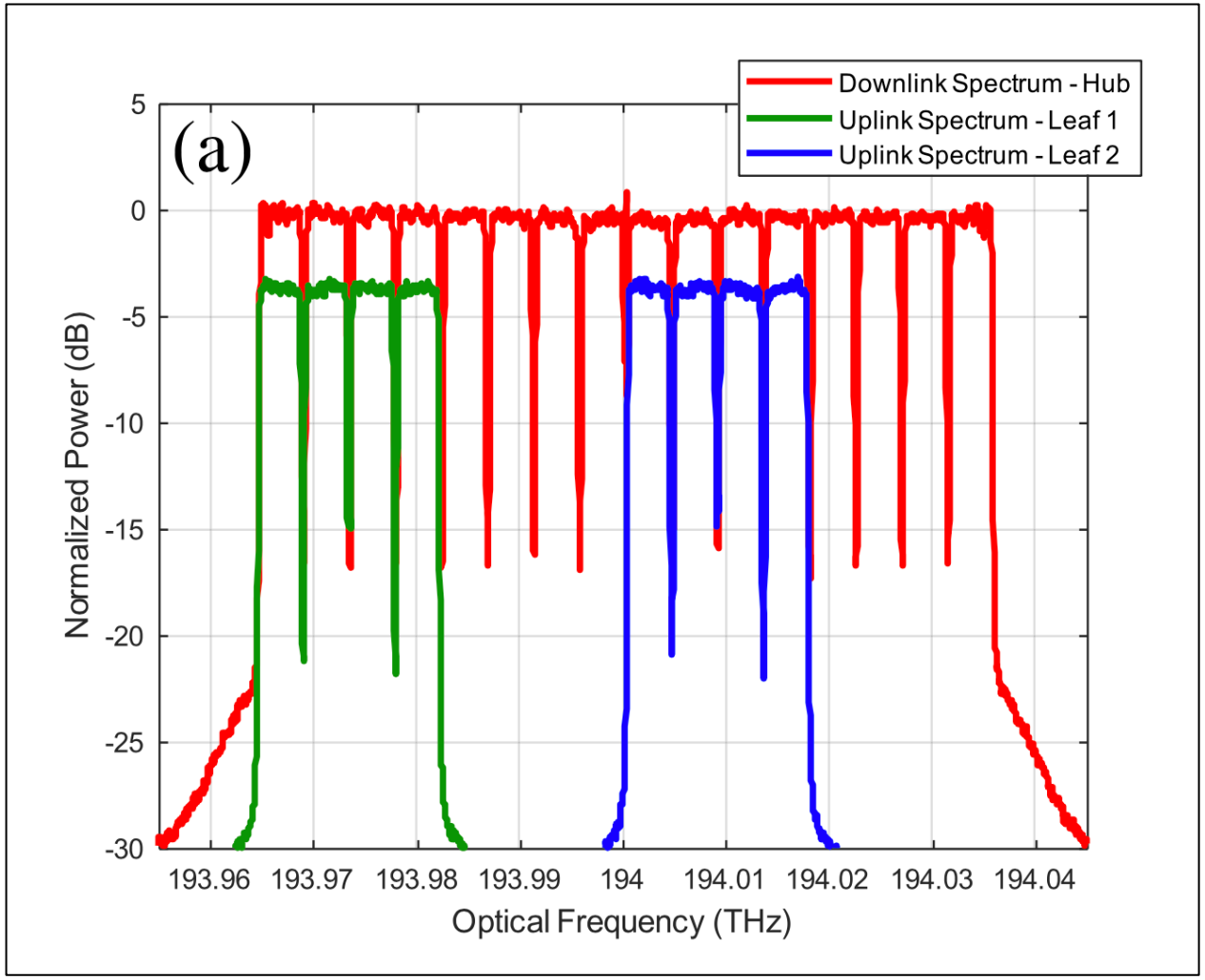
UP TO 16 LEAFS TO 400G HUB

source: [7]

Outlook: DSCM (Digital SubCarrier Multiplexing)



source: [7]



source: [8]

References

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
3. Lumentum Operations LLC, https://www.lumentum.com/en/products/400g-zrzr-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, 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)