# NANOG Presentation

## Navigating High-Speed Transceiver Challenges: Evolution, Impairments, and Dispersion

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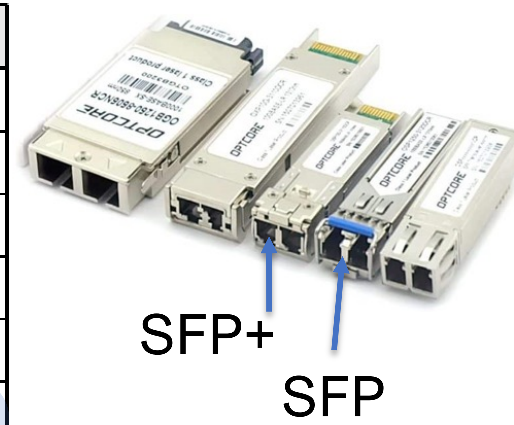
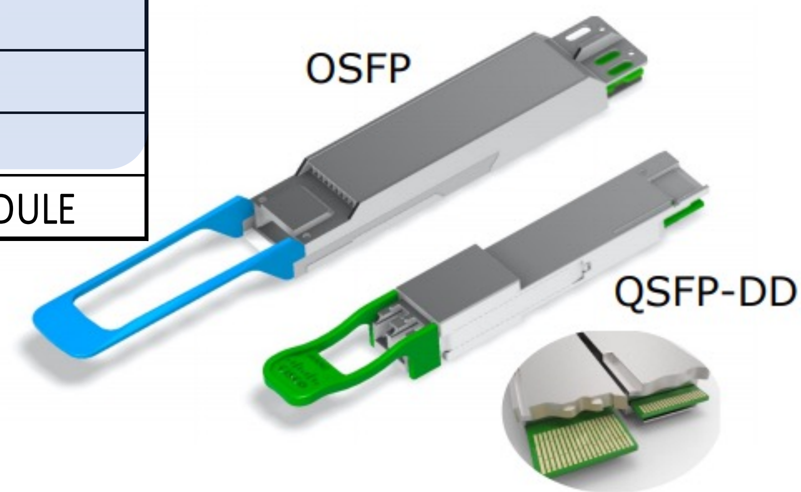
# Transceiver form factor

EXFO

| Year | Type | Discription |
|---|---|---|
| 1995 | **GBIC** | Gigabit Interface Converter |
| 2000 | **SFP** | Small Form Factor Pluggable |
| 2001 | **XENPAK** | 10 Gigabit Ethernet Transceiver Package |
| 2002 | **X2** | X2 10 Gigabit Ethernet Transceiver |
| 2005 | **XFP** | 10 Gigabit Small Form Factor Plaggable |
| 2009 | **SFP+** | Enhenced Small Form Factor Plaggable |
| 2010 | **QSFP+** | 4X 10Gb/s Pluggable Transceiver |
| 2012 | **QSFP28** | 4X 28Gb/s Pluggable Transceiver |
| 2016 | **QSFP-DD** | QSFP Double Density |
| 2017 | **OSFP** | OCTAL SMALL FORM FACTOR PLUGGABLE MODULE |

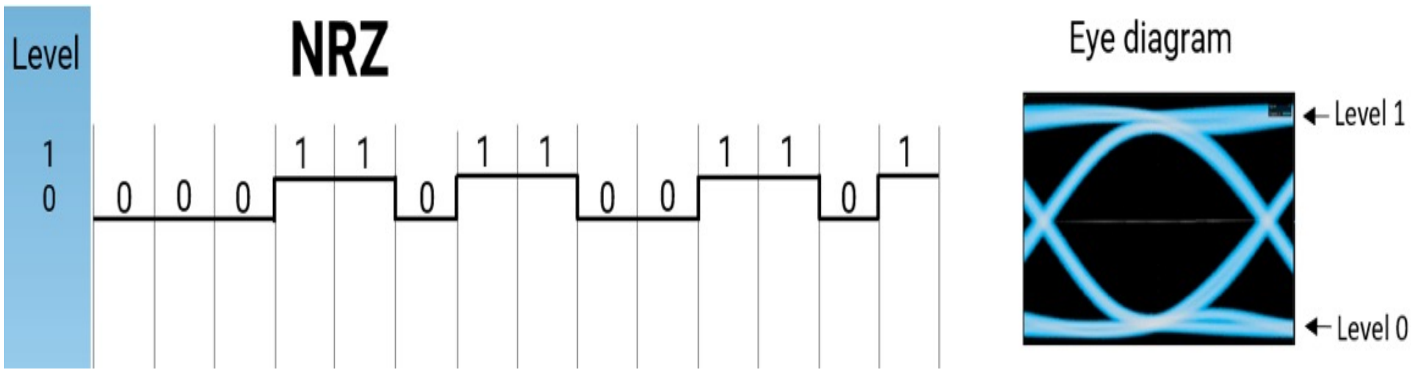



NANOG

# NRZ VS PAM4

## Non-Return to Zero (NRZ)

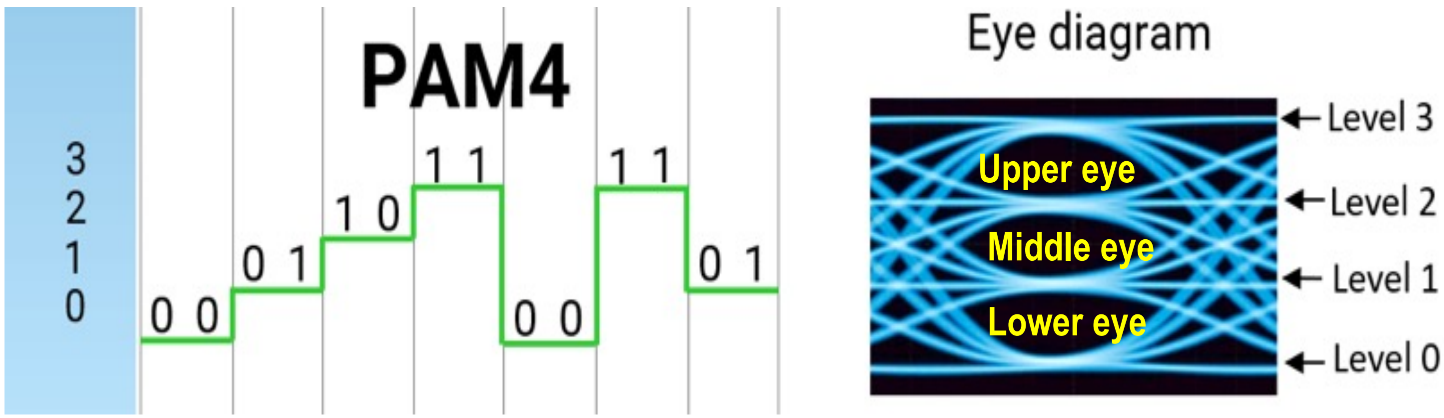



- NRZ is a binary (two levels) modulation represented by logic 0 and logic 1
- NRZ transmits one bit per symbol
- NRZ modulation served as the base of modern high-speed interfaces until 2012
- NRZ is PAM2 with 1 bit/symbol

# NRZ VS PAM4

## Pulsed-Amplitude Modulation 4 levels (PAM4)



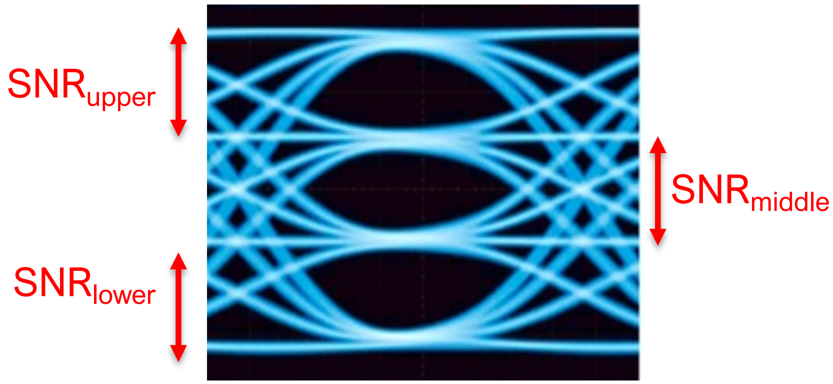

- PAM4 encodes four levels, represented by four combinations of two bits logic: 00, 01, 10 and 11.
- The PAM4 eye diagram presents three eye openings and four levels.
- PAM4 transmits 2 bits per symbol

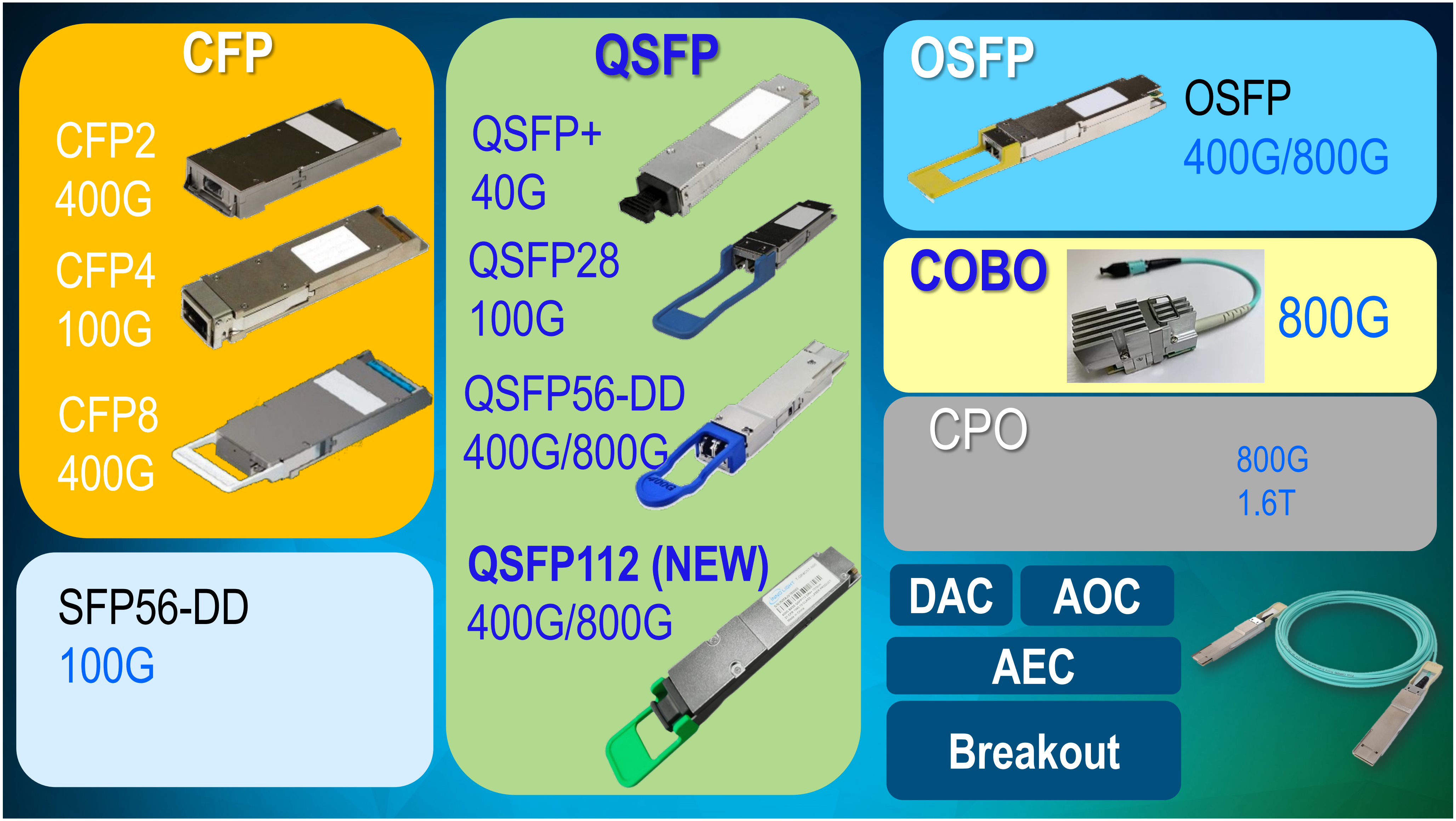
 

# Challenges introduced by PAM4

- PAM4 signal is more susceptible to noise: Signal to Noise Ratio (SNR) **divided by 3** compared to NRZ

- PAM4-based units **consume higher power** than a transceiver supporting NRZ because of the need for more advanced equalization

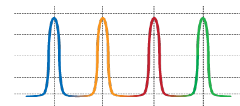


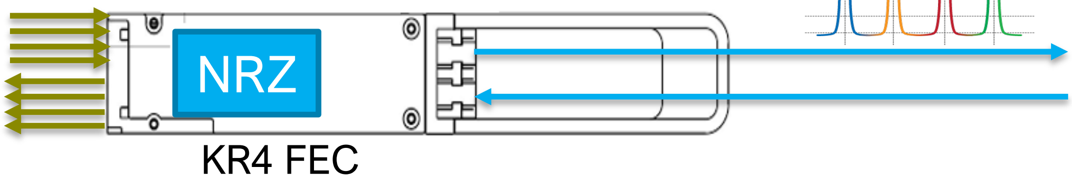

CFP
CFP2
400G
CFP4
100G
CFP8
400G
SFP56-DD
100G
QSFP
QSFP+
40G
QSFP28
100G
QSFP56-DD
400G/800G
QSFP112 (NEW)
400G/800G
OSFP
OSFP
400G/800G
COBO
800G
CPO
800G
1.6T
DAC
AOC
AEC
Breakout

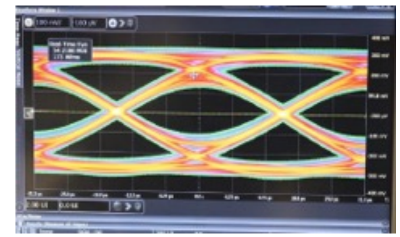
# Line rate evolution

## QSFP28-LR4

8x 25.78Gb/s
Electric lanes



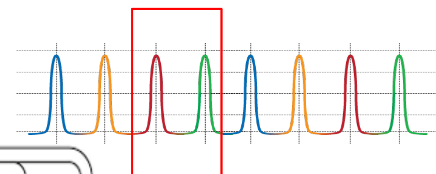


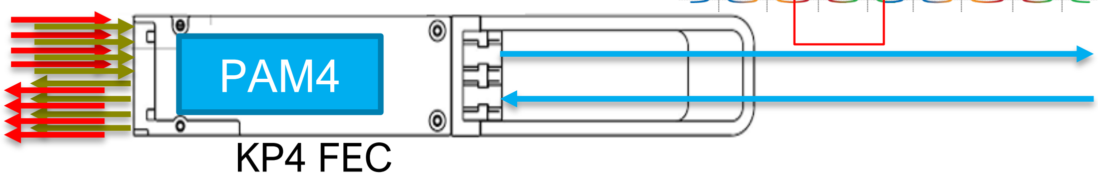



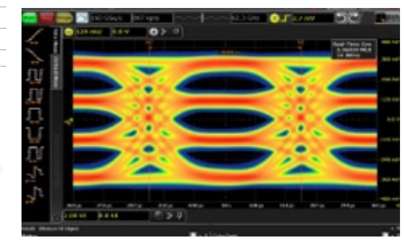
1ch

## QSFPDD-LR8

16 x 53.125Gb/s
Electric lanes



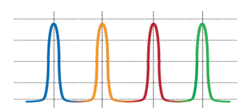


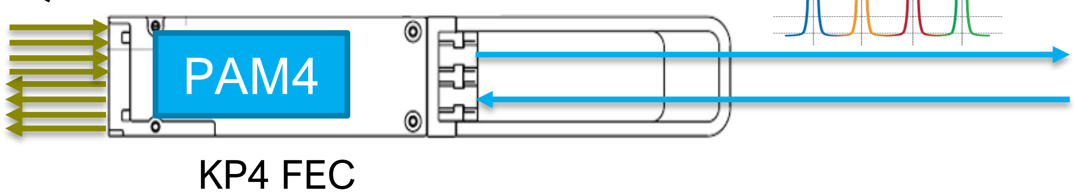



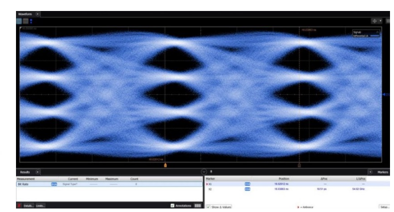
1ch

## QSFP112-LR4

8 x 106.25Gb/s
Electric lanes





1ch

Lasers

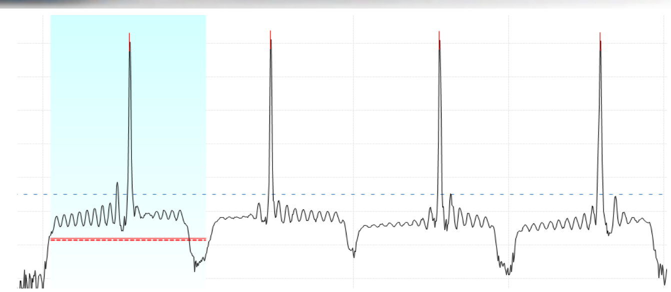
# 400G transceiver example

Host

Data:
16 x 50 Gbps

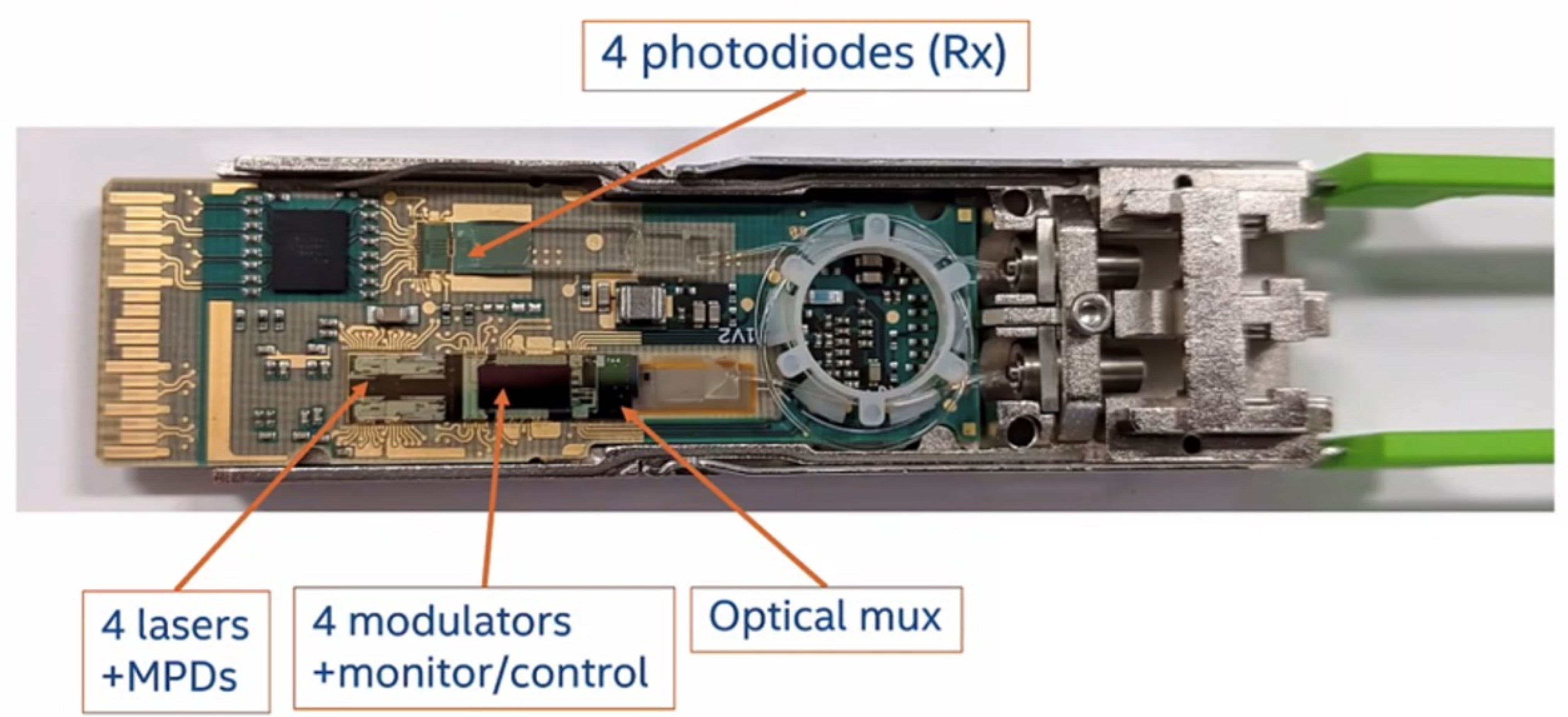
400GBase-LR4

Multiplexer= + Watts, + heat
Optical mux = + Watts, + heat



Signal: 4 x 100Gbps λ

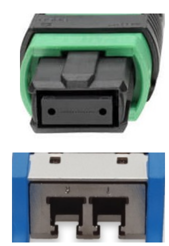
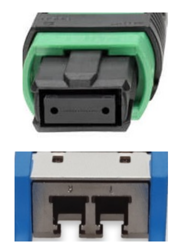
# FR4


4 photodiodes (Rx)
4 lasers
+MPDs
4 modulators
+monitor/control
Optical mux

# 100G transceiver types

| Distance | 1-3m | 100m | 0.5-2Km | 10-40Km | 80Km |
|---|---|---|---|---|---|
| Module | 100G-DAC<br>100G-AOC | 100G-SR4 | 100G-CWDM4<br>100G-PCM4<br>100G-FR1/DR1 | 100G-LR4<br>100G-ER4 | 100G-ZR4 |
| Media | Copper/AOC | MMF | SMF | SMF | SMF |




# 400G transceiver types

**Distance**

3m | 100m | 0.5-2Km | 10Km | +80Km

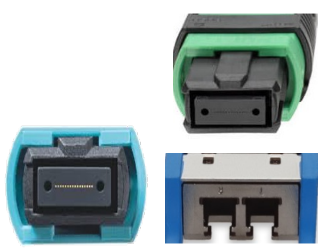
**Module**

- 3m: 400G-CR8, 400G-AOC
- 100m: 400G-SR8, 400G-SR4.2, 400G-DR4
- 0.5-2Km: 400G-DR4+, 400G-FR4
- 10Km: 400G-LR4, 400G-LR8, 400G-DR4++
- +80Km: 400G-ZR, 400G-ZR+

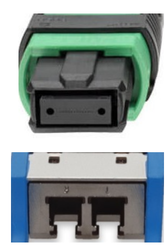
**Media**

Copper/AOC

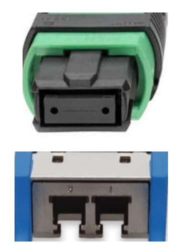
MMF SMF



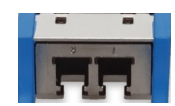
SMF



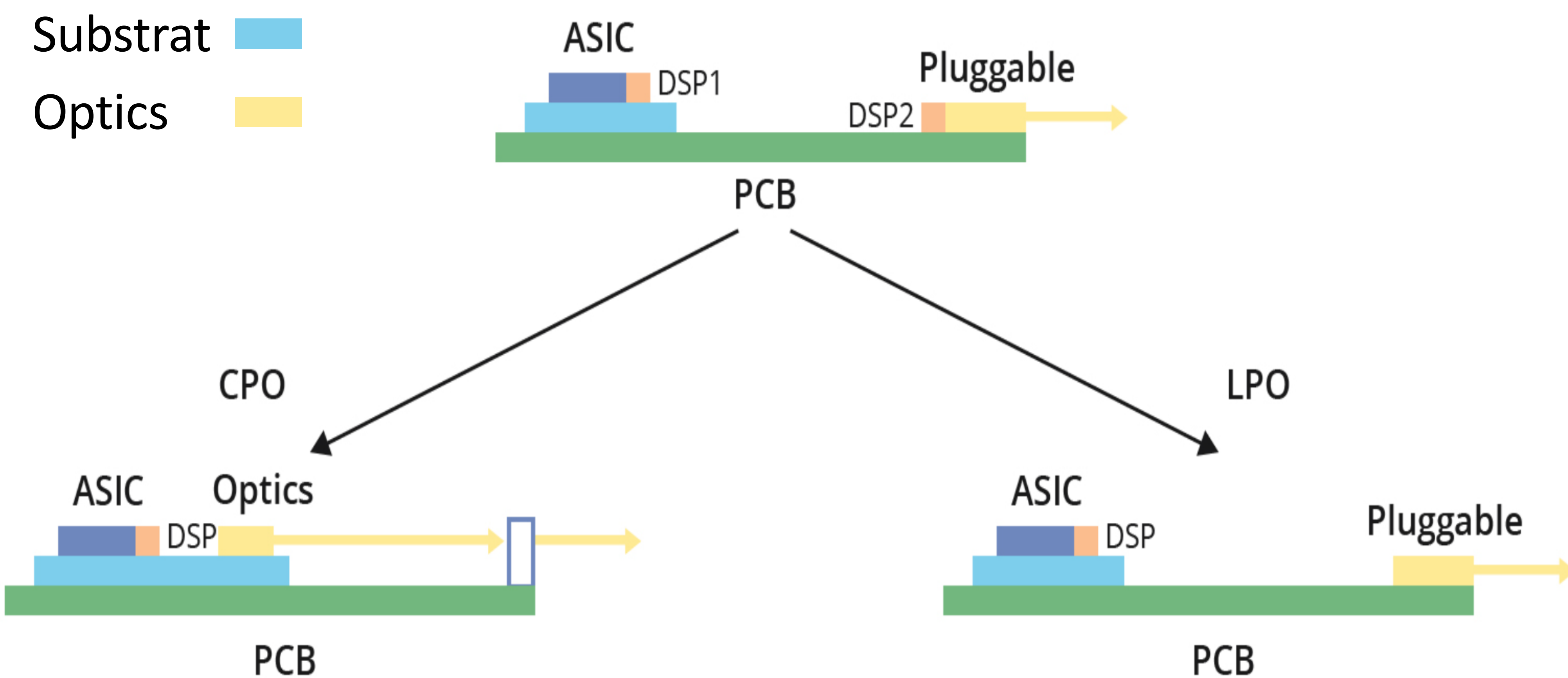
SMF



SMF



# Evolution: CPO to LPO



# What is coherent optics?

**COHERENT LINE CARD**

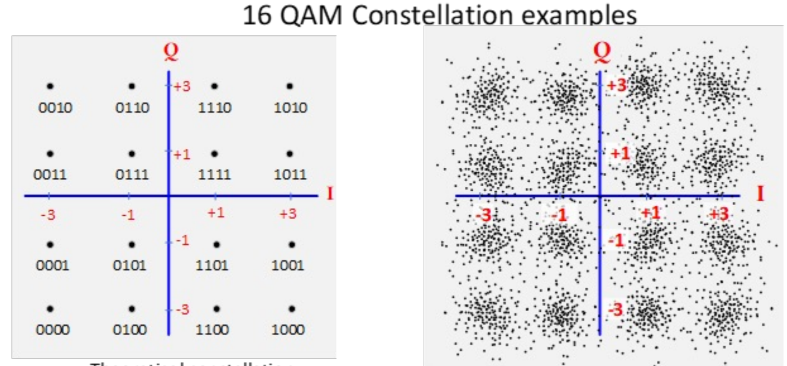
OTN card

**COHERENT OPTICS**

400G Ethernet support up to 1000 km

Smaller footprint to transport high-bandwidth interconnections over DWDM system for DC-i

16 QAM Constellation examples




Theoretical constellation
Gray coded

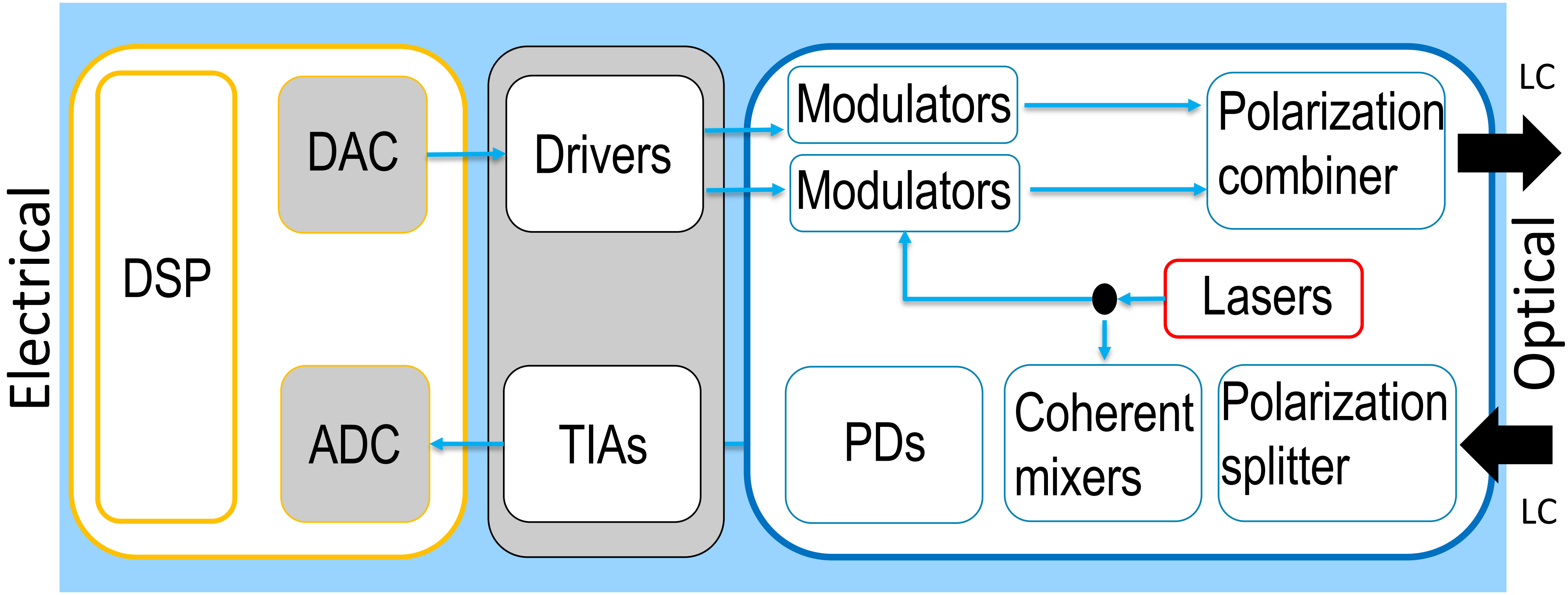
Noisy constellation

Coherent optic uses amplitude and phase modulation of light

# Evolution: Coherent

## 400ZR: 120Km, Tunable; Modulation:16QAM

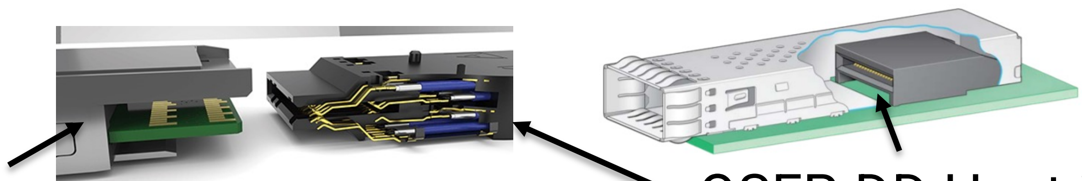


# CMIS

CMIS: Common Management Interface Specification

C-CMIS: Coherent Common Management Interface Specification.



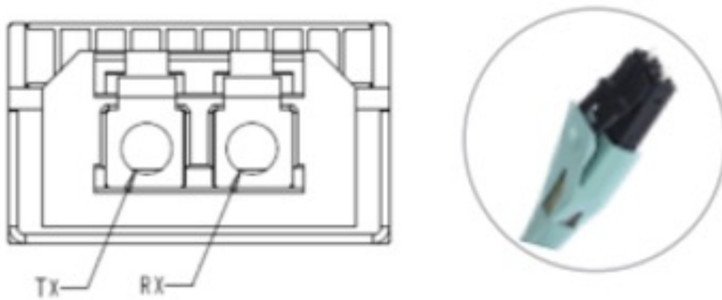
Compliant module

QSFP-DD Host interface

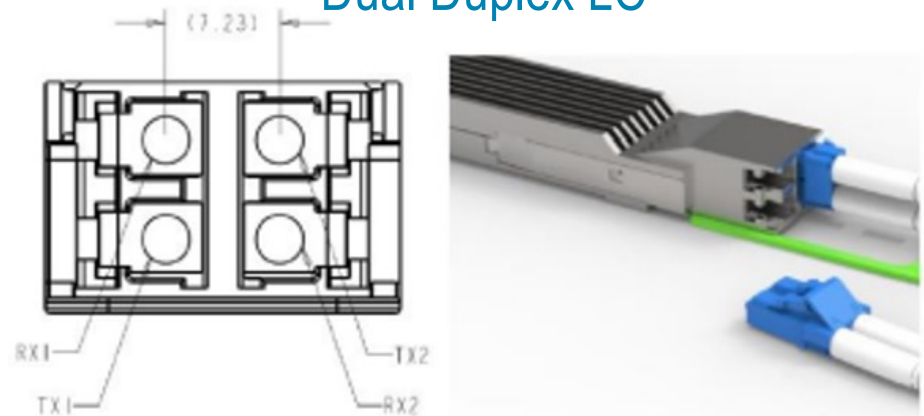
- Open communication between module and host
- Interface control

# Evolution of optical connectors for 800Gbps

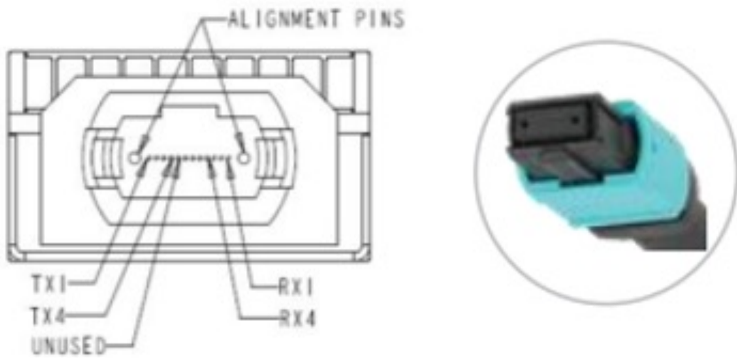
## Duplex LC



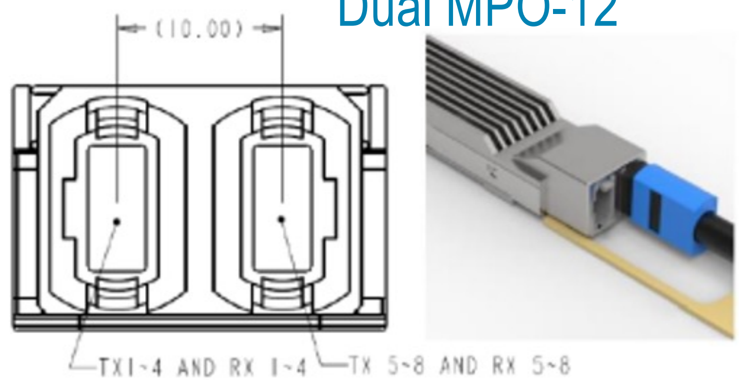

## Dual Duplex LC



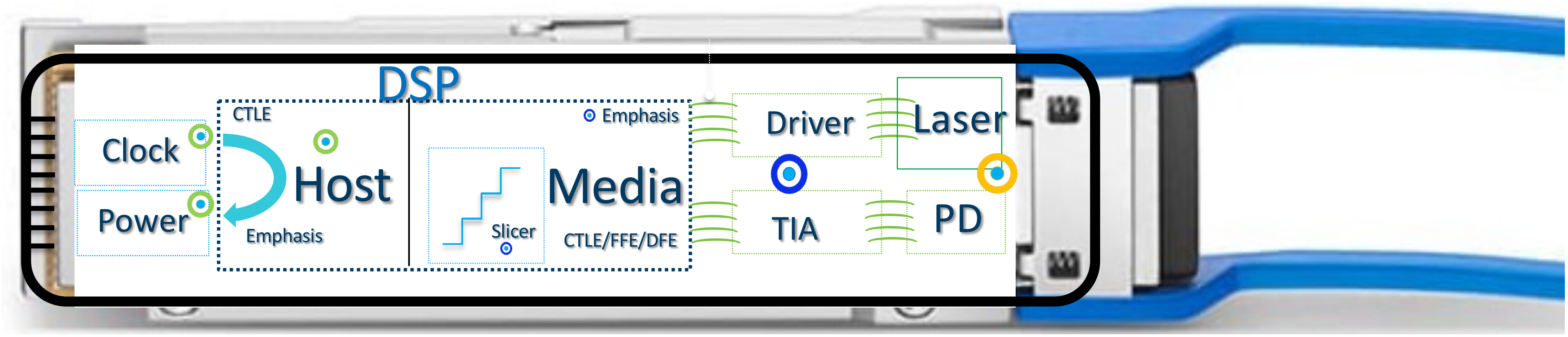

## MPO-12




## Dual MPO-12



# Sources of errors in transceivers – Quality matters




**Thermal Noise**: Random errors.
**Power Fluctuations**: Random errors.
**Laser low Quality and Stability**: Increase error rate.
**Photodiode Sensitivity and Linearity**: Can introduce error.



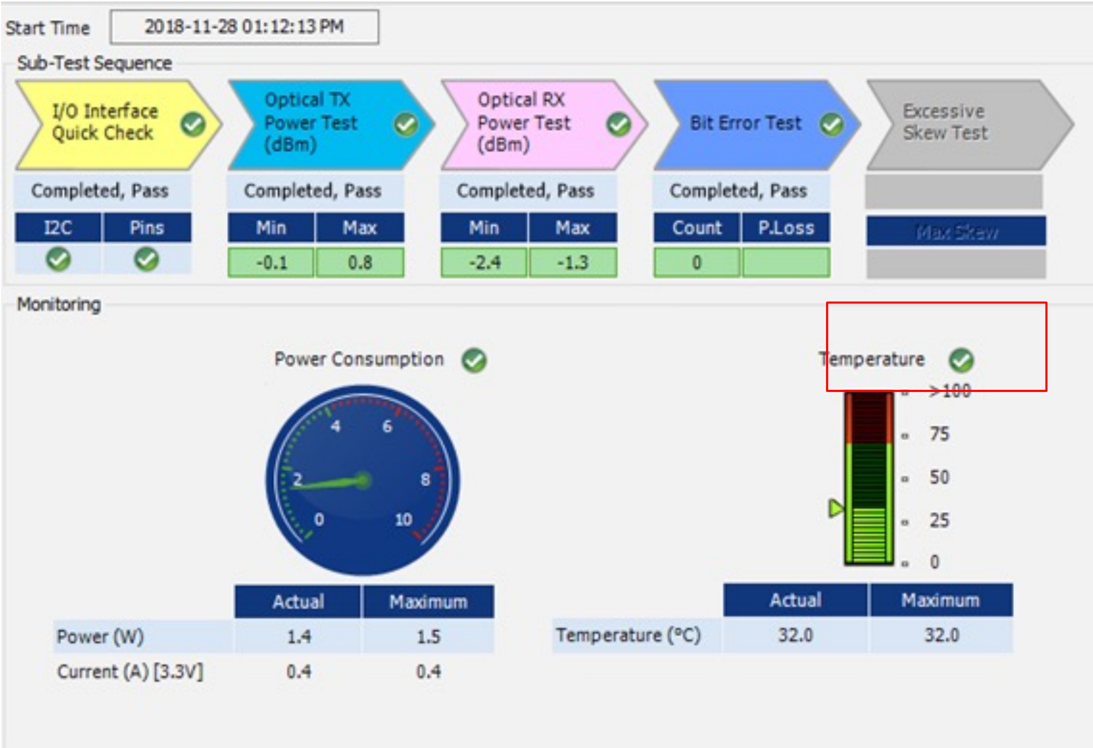
 

# iOptics – Transceiver validation

iOptics Intelligent test application that quickly **validates** transceiver

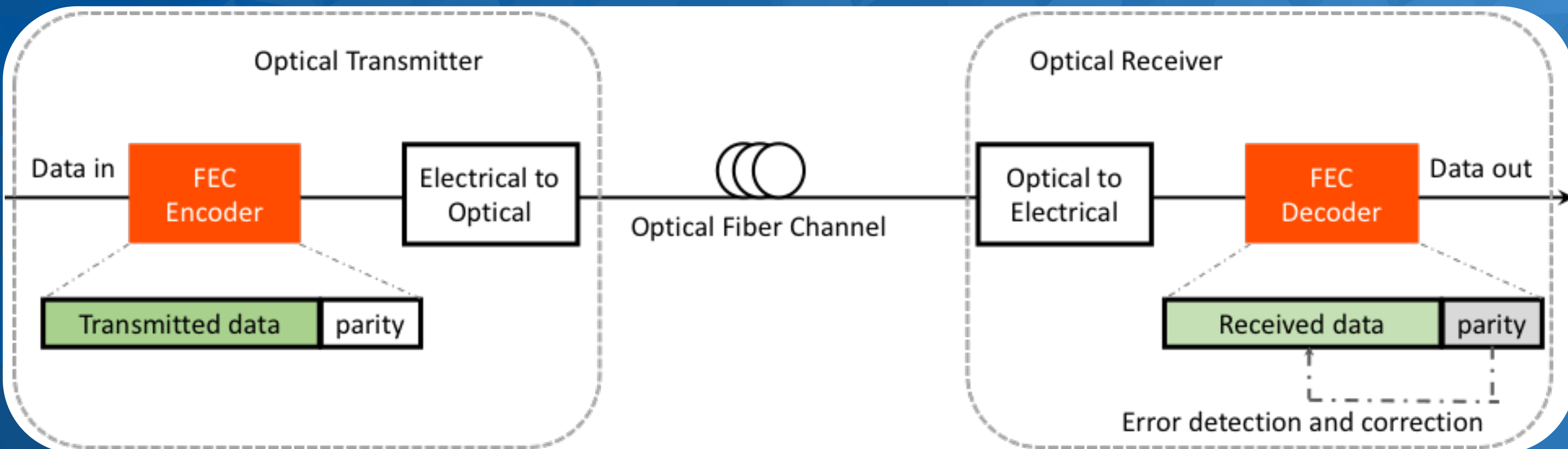
**Testing sequence:**

1. MDIO/I2C Quick check
2. Optical TX level and stability
3. Optical RX level and stability
4. BER stress Test
5. Power monitoring
6. Temperature monitoring

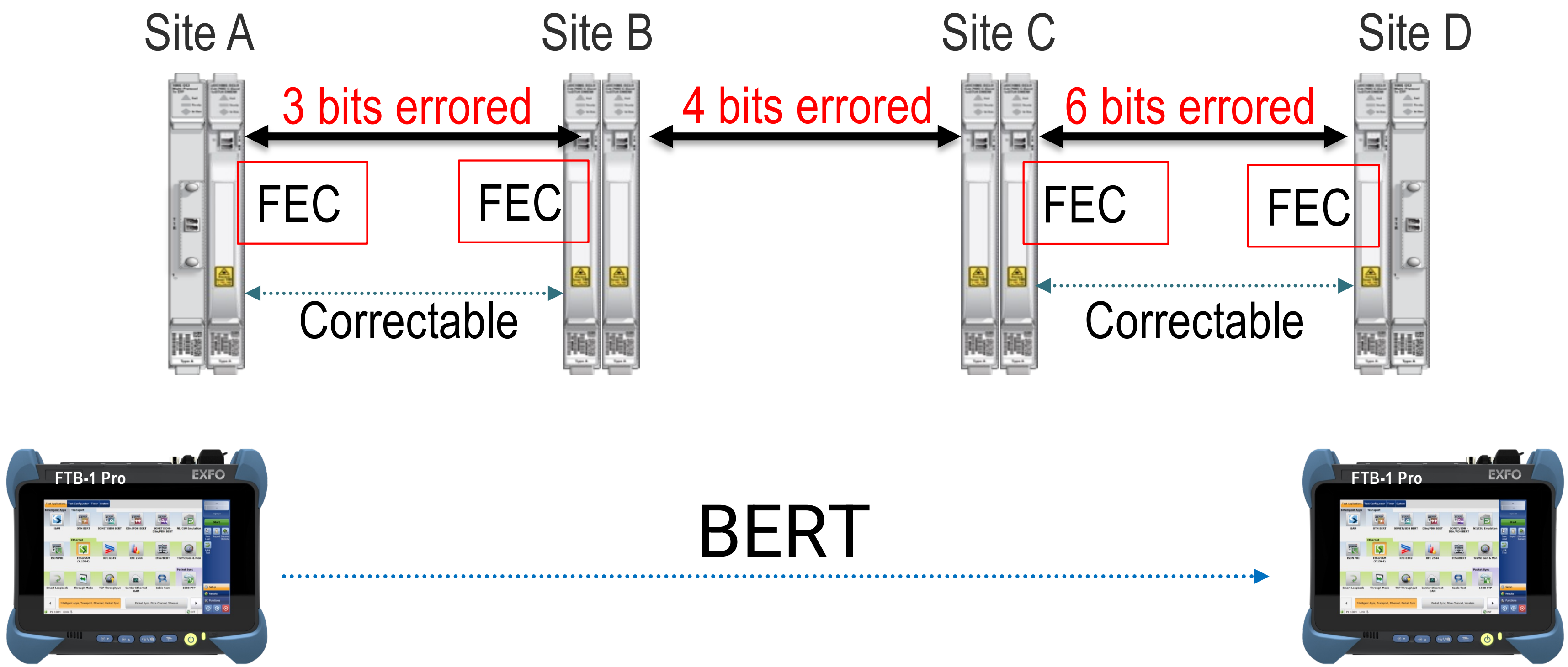


# FEC

- Definition and Function: Forward Error Correction (FEC) is a coding technique that adds redundancy to transmitted data, enabling receivers to detect and correct errors without needing retransmission.
- Application and Standards: FEC is essential for ensuring reliable transmission in high-speed networks (100G+), as specified by IEEE standards like 802.3bs



# FEC correction




Total errors measured: 4 bits errored

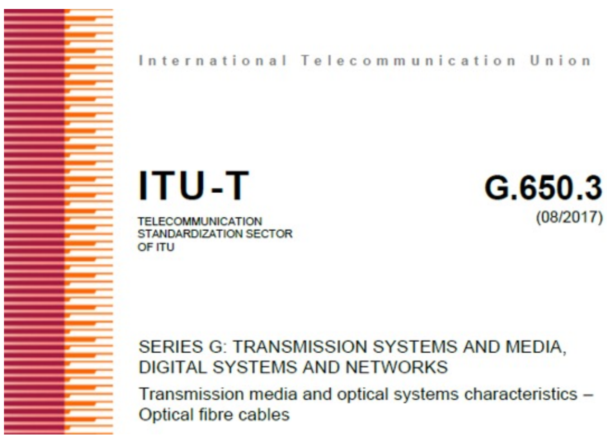
# Types of RS-FEC

| HD: hard decision<br>SD: soft decision | Coding overhead rate | Net coding gain (NCG) dB @10E-15 | pre-FEC BER threshold |
|---|---|---|---|
| GFEC (HD) | 6.69% | 6.2 | 8.0E-5 |
| EFEC (HD) | 6.69% | 8.67 | 2.17E-3 |
| 100G: Staircase FEC (HD) | 6.69% | 9.38 | 4.5E-3 |
| 200G: oFEC (SD) | 15.3% | 11.1 for QPSK<br>11.6 for QAM16 | 2.0E-2 |
| 400G: cFEC (SD) | 14.8% | 10.4 for QPSK<br>10.8 for QAM16 | 1.22E-2 |

# Bandwidth limitation induced by dispersion

# Advanced G.650.3 Recommendations

- Dispersion testing completes the recommendations for fiber characterization.
- Two types of dispersion:
  - Chromatic Dispersion (CD)
  - Polarization Mode Dispersion (PMD)


International Telecommunication Union

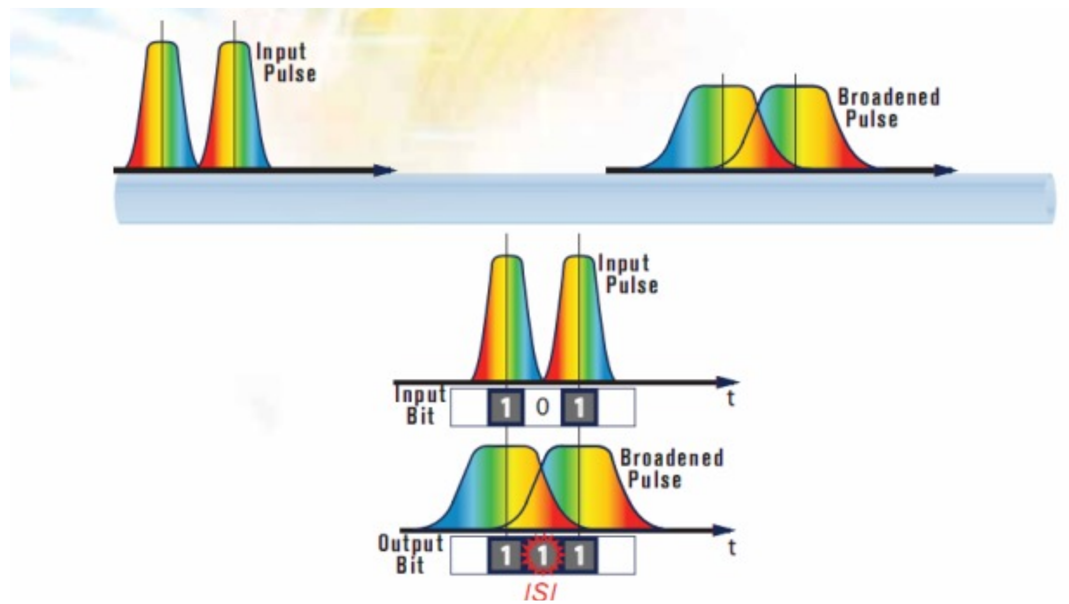
ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

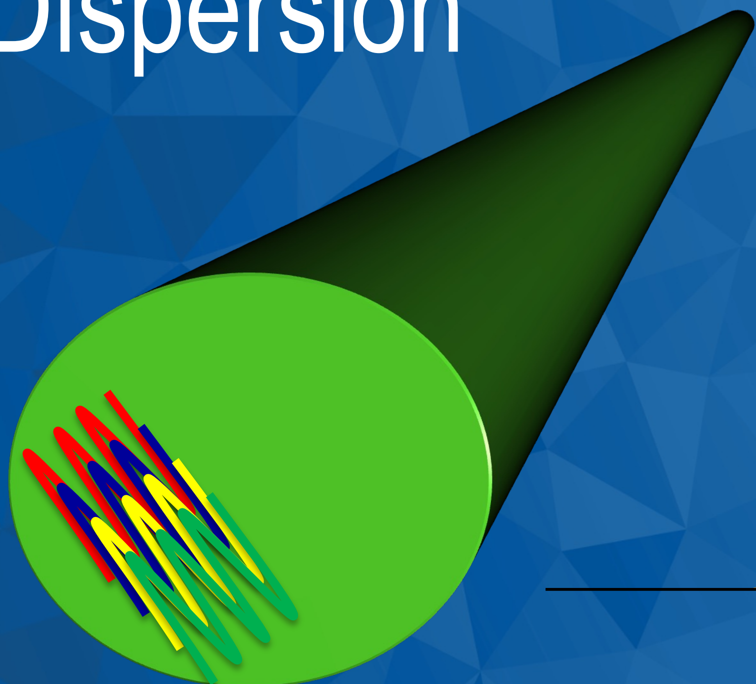
G.650.3
(08/2017)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA,
DIGITAL SYSTEMS AND NETWORKS

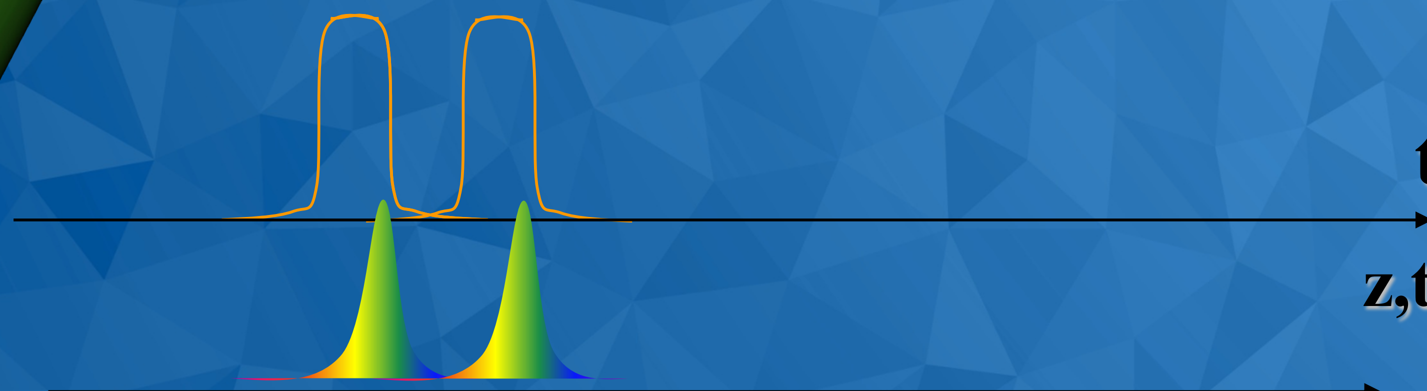
Transmission media and optical systems characteristics –
Optical fibre cables

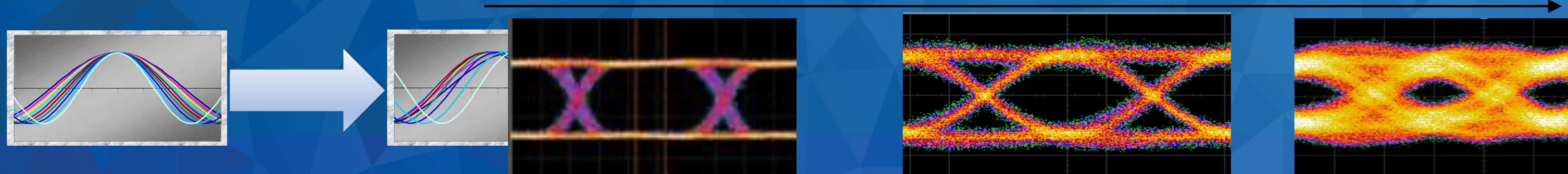


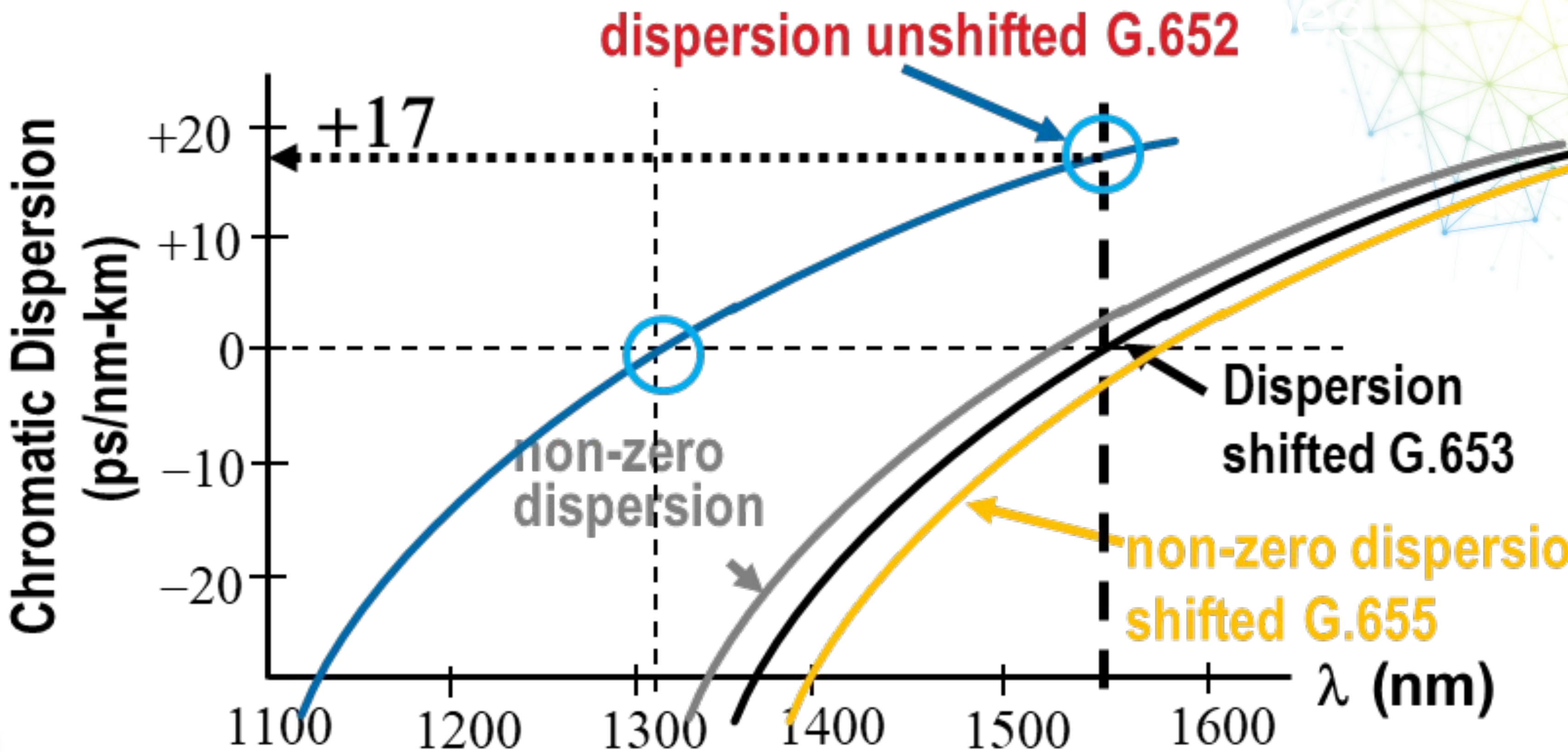
# Chromatic Dispersion



- Different wavelengths travel at different speeds in a fiber, causing pulse broadening
- Limits how fast and how far a signal will travel
- Higher bit rates are less robust



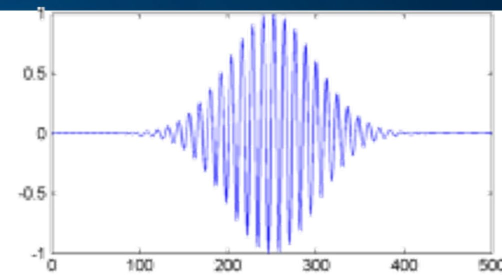


dispersion unshifted G.652
+17
Chromatic Dispersion (ps/nm-km)
+20
+10
0
−10
−20
non-zero dispersion
Dispersion shifted G.653
non-zero dispersion shifted G.655
1100
1200
1300
1400
1500
1600
λ (nm)

# CD per type

| | | Attenuation (dB/km) | | Chromatic Dispersion (ps/nm*km) | |
|---|---|---|---|---|---|
| ***Fiber Type*** | ***ITU Specification*** | ***1310 nm*** | ***1550 nm*** | ***1310 nm*** | ***1550 nm*** |
| 9/125 Standard Single-mode | G.652 | 0.32 | 0.22 | 0 | 17 |
| 9/125 Cut-off shifted (pure Silica Core) | G.654 | 0.32* | 0.17 | 0 | 18 |
| 9/125 Dispersion Shifted | G.653 | 0.32* | 0.22 | -15 | 0 |
| 9/125 NZDSF | G.655 | 0.35* | 0.22 | N/A | 4-6 |

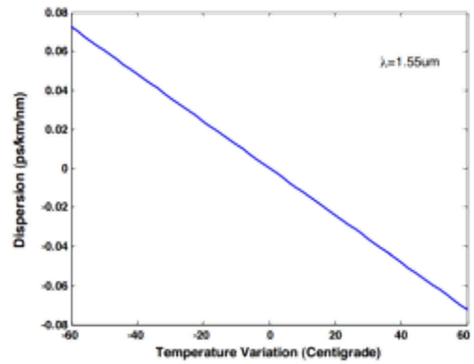
# Facts About Chromatic Dispersion




Chromatic dispersion (CD) is linear:

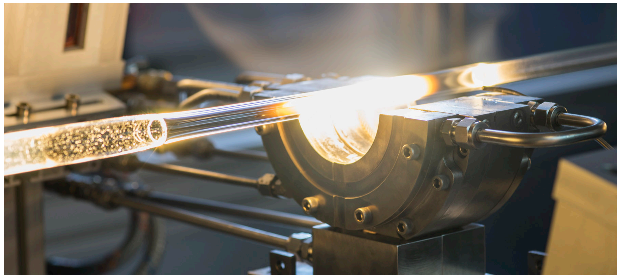
CD increases proportionally with distance

17ps/(nm-km) +/-2 nm @ 1550 nm G.652



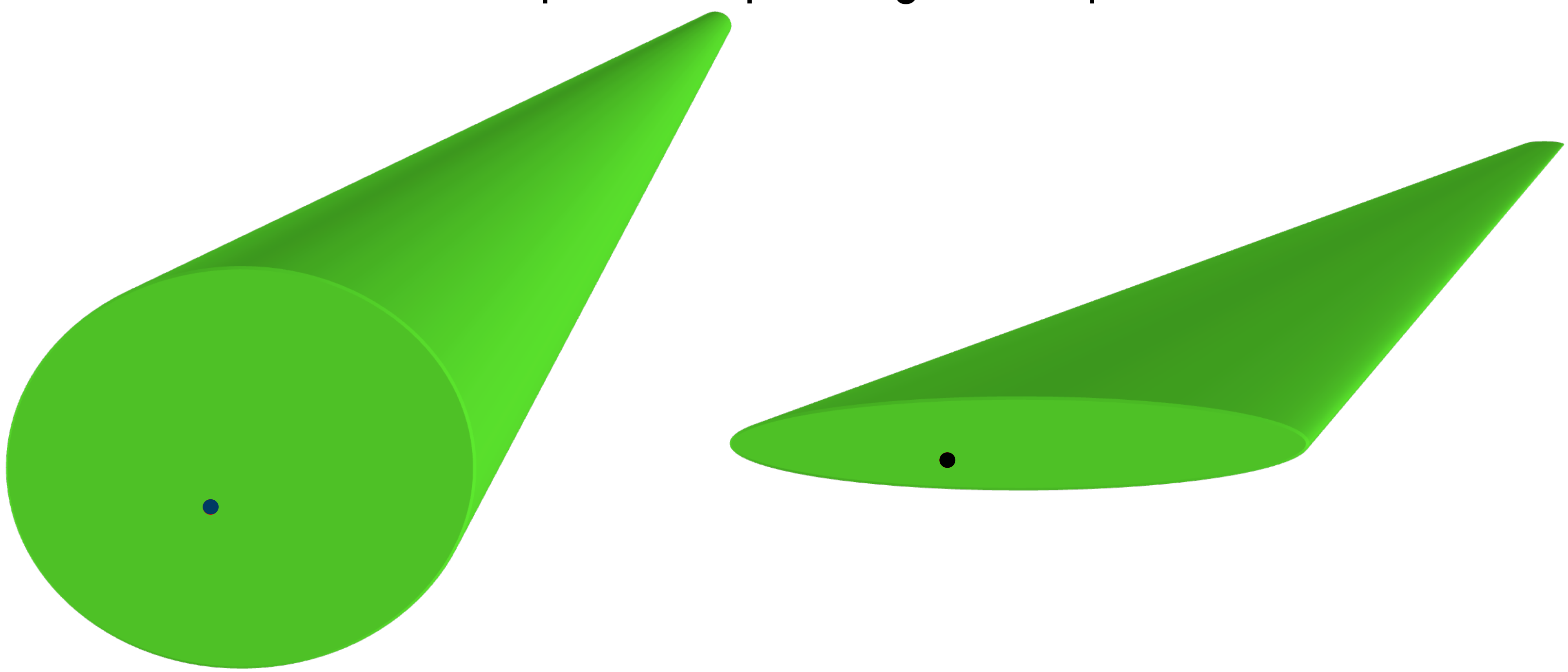

CD does not change (much) over time

CD properties are set during manufacturing. The values measured are used to adjust the compensation process and to select the optimum set of transmitter/receiver.



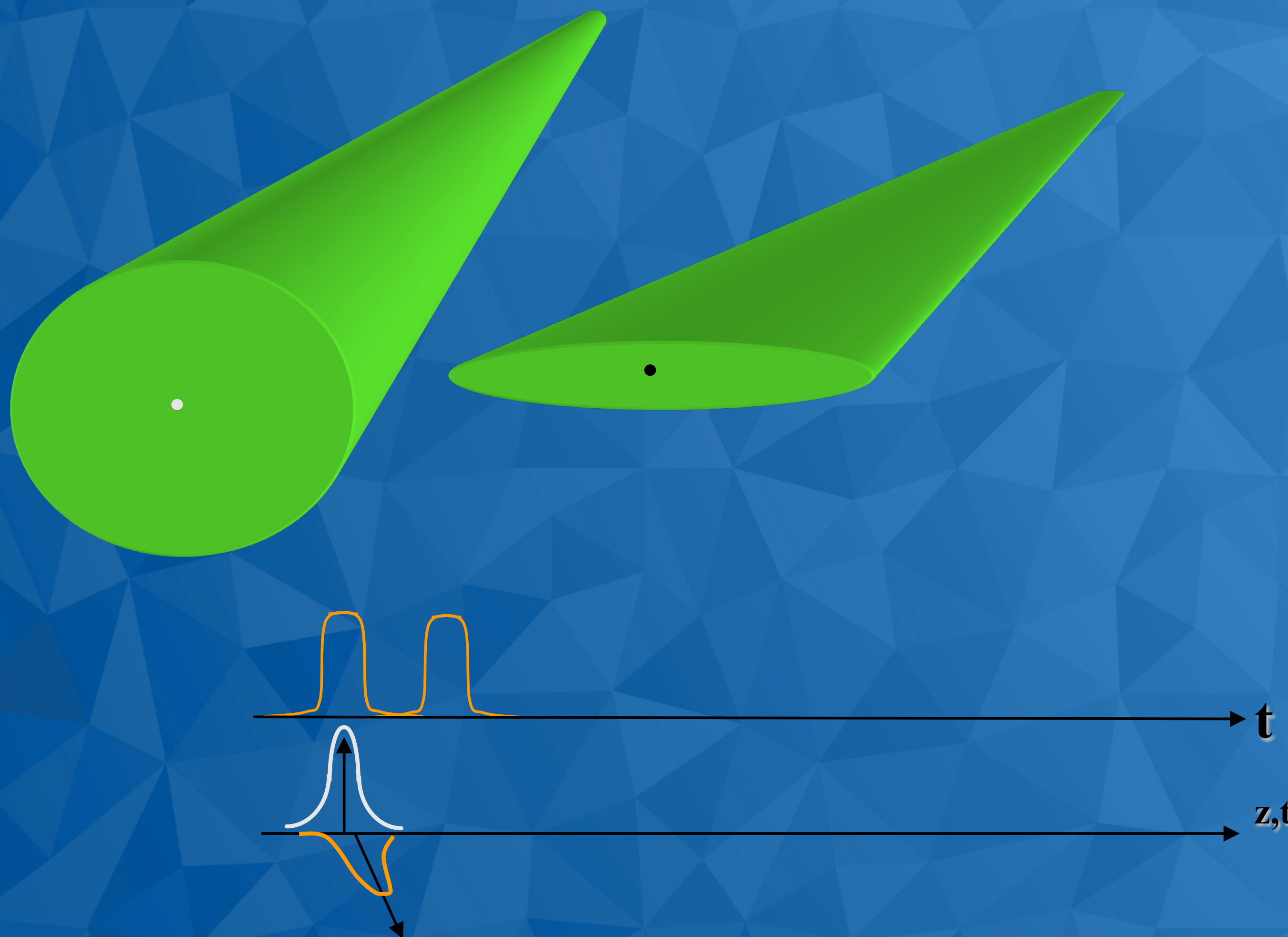
# Polarization Mode Dispersion

- Pulses travel at different speeds depending on the polarization.

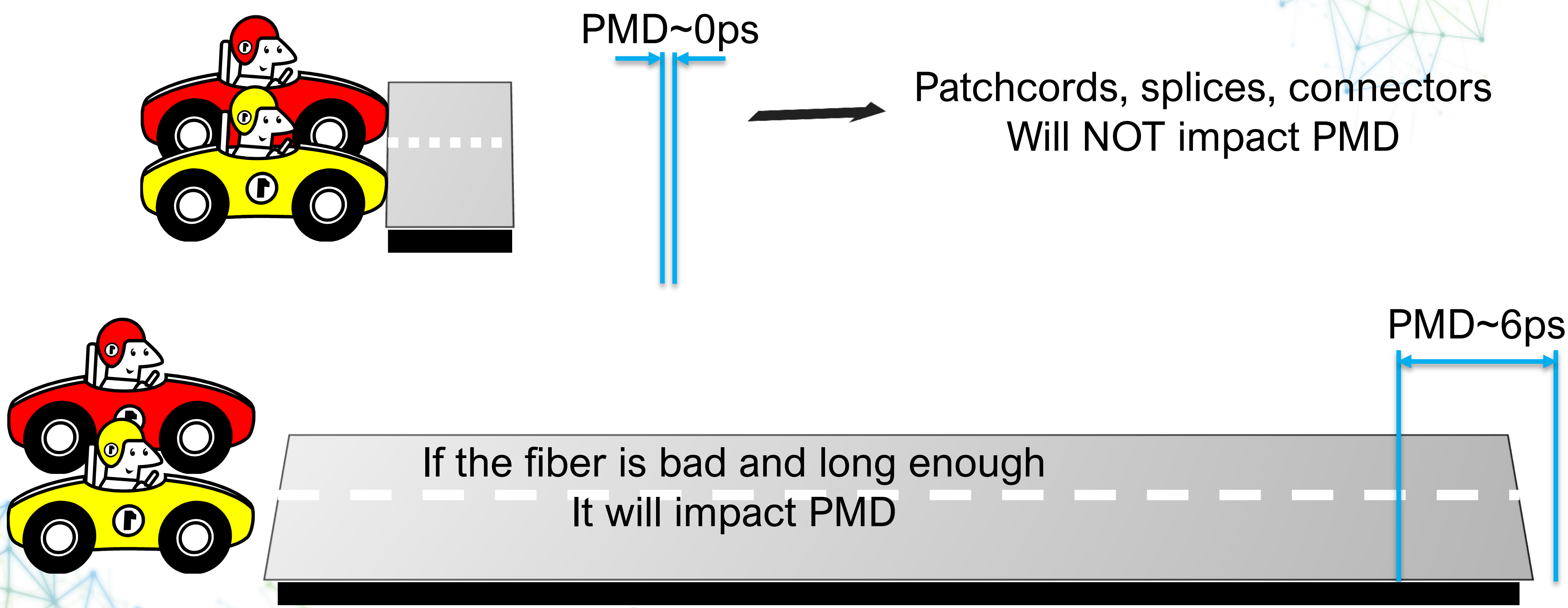


- If PMD = 0: PSPs travel at same speed.
- If PMD ≠ 0: PSPs do not travel at same speed.

# Polarization Mode Dispersion PMD



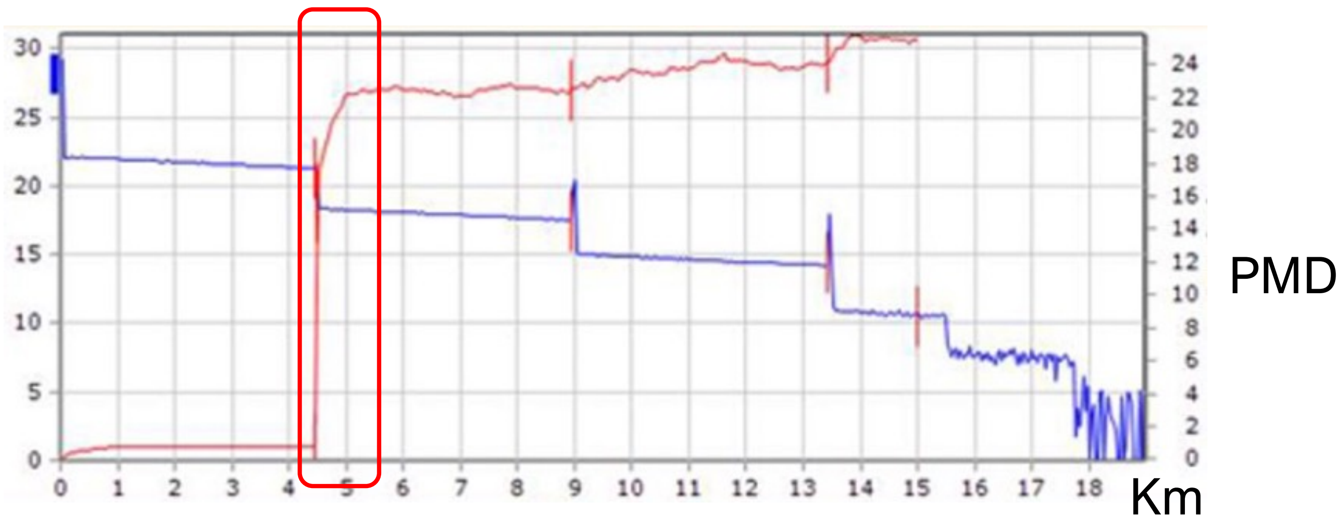
# PMD and delay accumulation…




Fact: PMD accumulates with the $\sqrt{distance}$

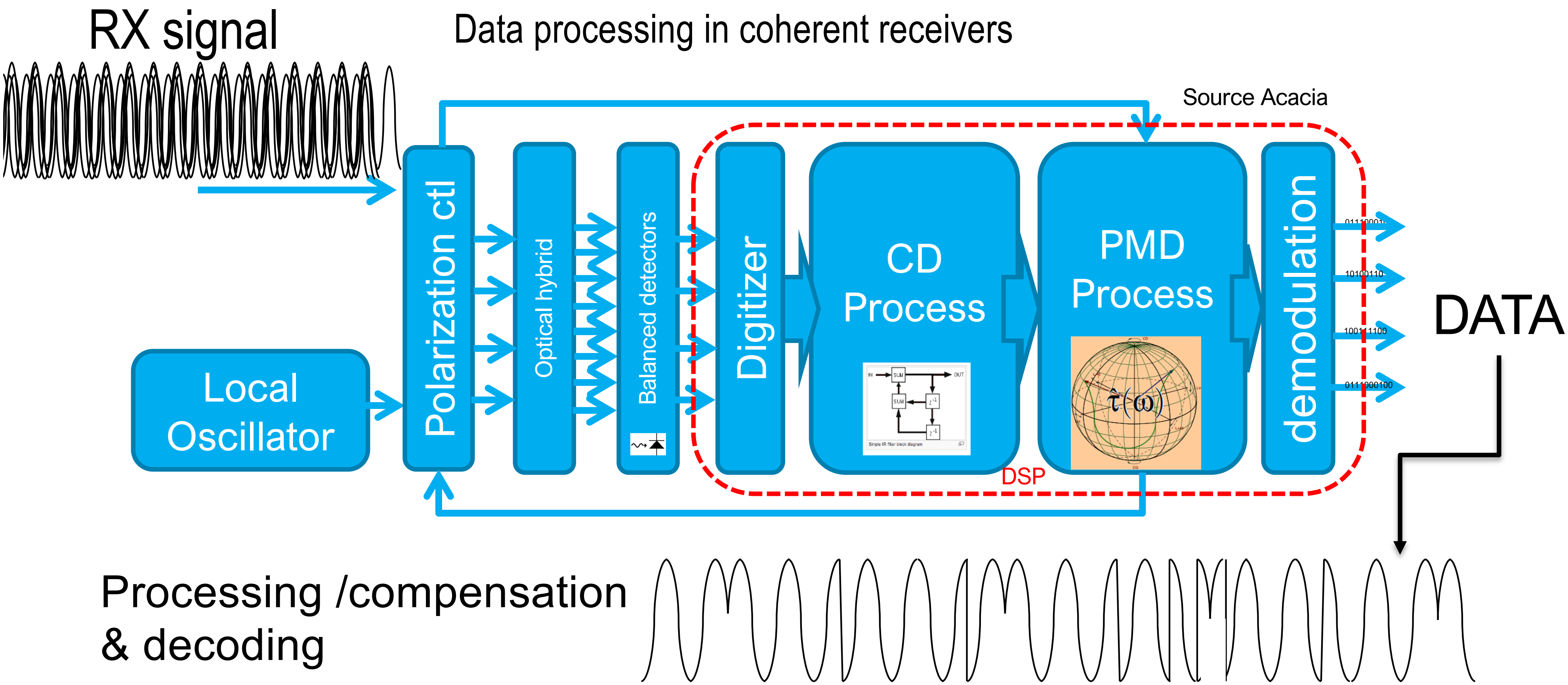
# Facts about Polarization Mode Dispersion

A good fiber is a 0 ps fiber.
PMD is a defect, such as high loss or a macrobend.
PMD coef < 0.2 ps√km.




If PMD "FAILs" in the field, the main PMD contribution can be identified, and the identified fiber section should be replaced

# Dispersion Compensation in coherent transceivers



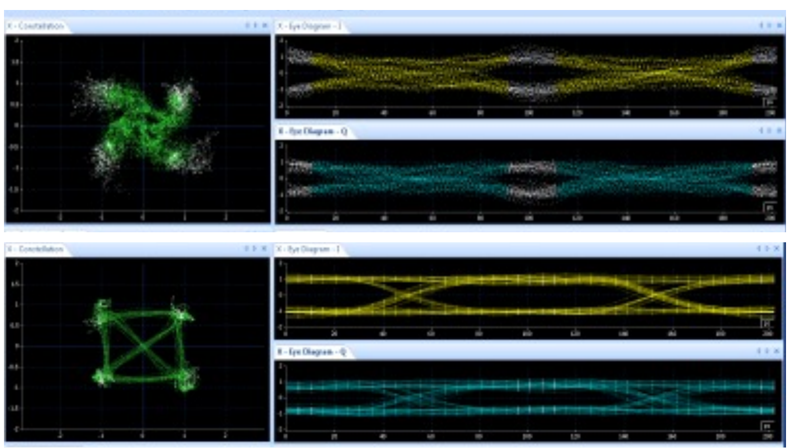

We can only compensate for effects that are predictable, using a mathematical model.

# Dispersions Compensation

**CD compensation is linear and stable:**

Could be filtered out with digital filters (like FIR, IIR…)

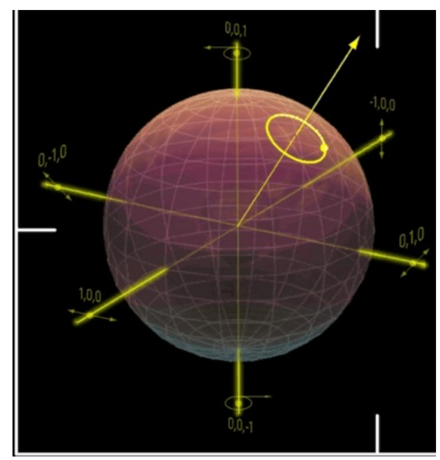
Post compensation of more than 70,000 ps/nm could be achieved



**PMD compensation is linear but not stable:**

PMD needs to be tracked and re-evaluated frequently. Compensation variates.

The ability to compensate is limited by the efficiency, the complexity and the speed of the algorithms



# Optical Signal to Noise Ratio (OSNR) maters! It's not magic.

| Key Parameters | 400ZR | 400ZR+ | 400G Long Haul / Multi-Span |
|---|---|---|---|
| From Factor | DD-QSFP | DD-QSFP | CFP2-DCO |
| Baud Rate | 60 GBaud | 60~63 GBaud | 67 GBaud |
| Modulation | 16QAM | 16QAM | 16QAM-PS |
| TX Output | ≥ -10 dBm | ≥ -10 dBm | ≥ 0 dBm |
| TX OSNR | --- | ≥ 40 dB | ≥ 60 dB |
| OOB OSNR | --- | ≥ 40 dB | ≥ 55 dB |
| rOSNR | ≤ 26 dB | ≤ 24 dB | ≤ 21 dB |

# Questions?