

400G PAM4 High-Speed Client-Side Interface

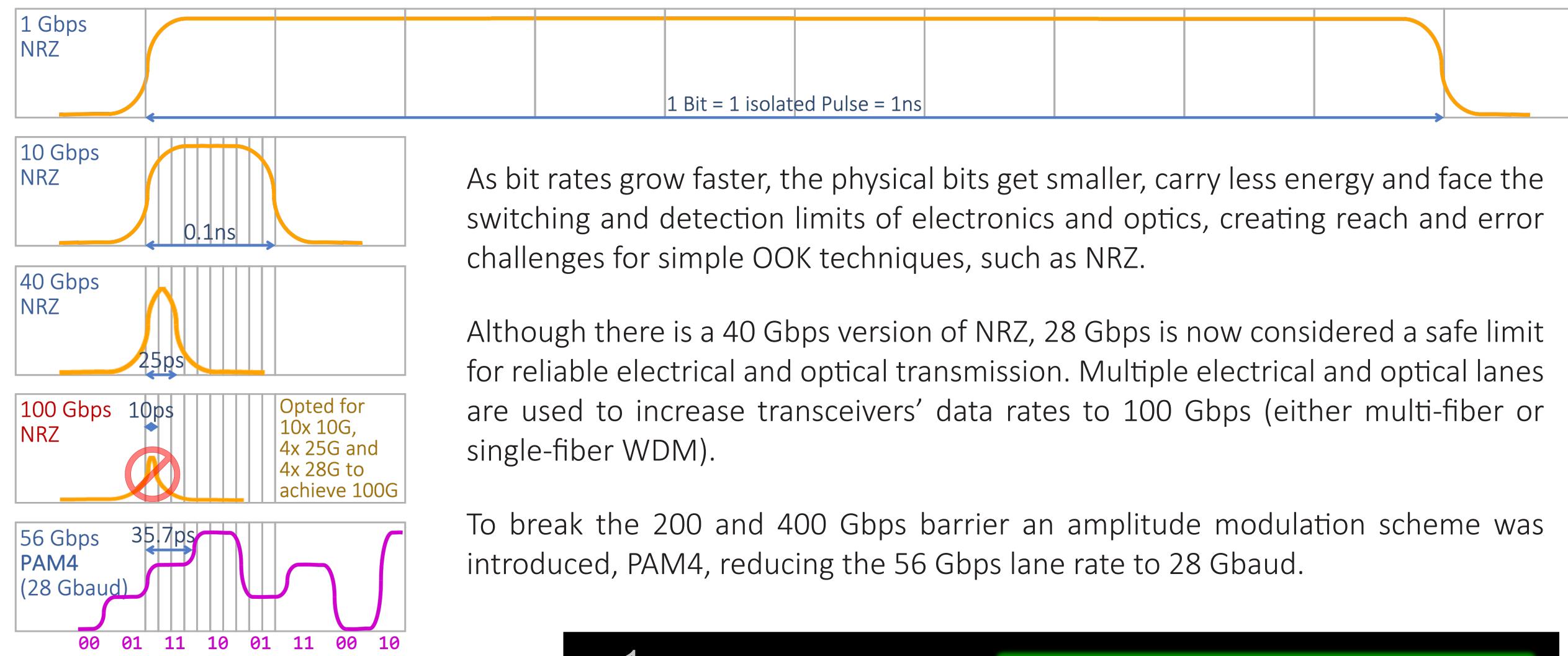
OSFP & QSFP-DD Optical Transceiver Technologies



PAM4 Modulation vs. Legacy NRZ-OOK

The Need for Modulation

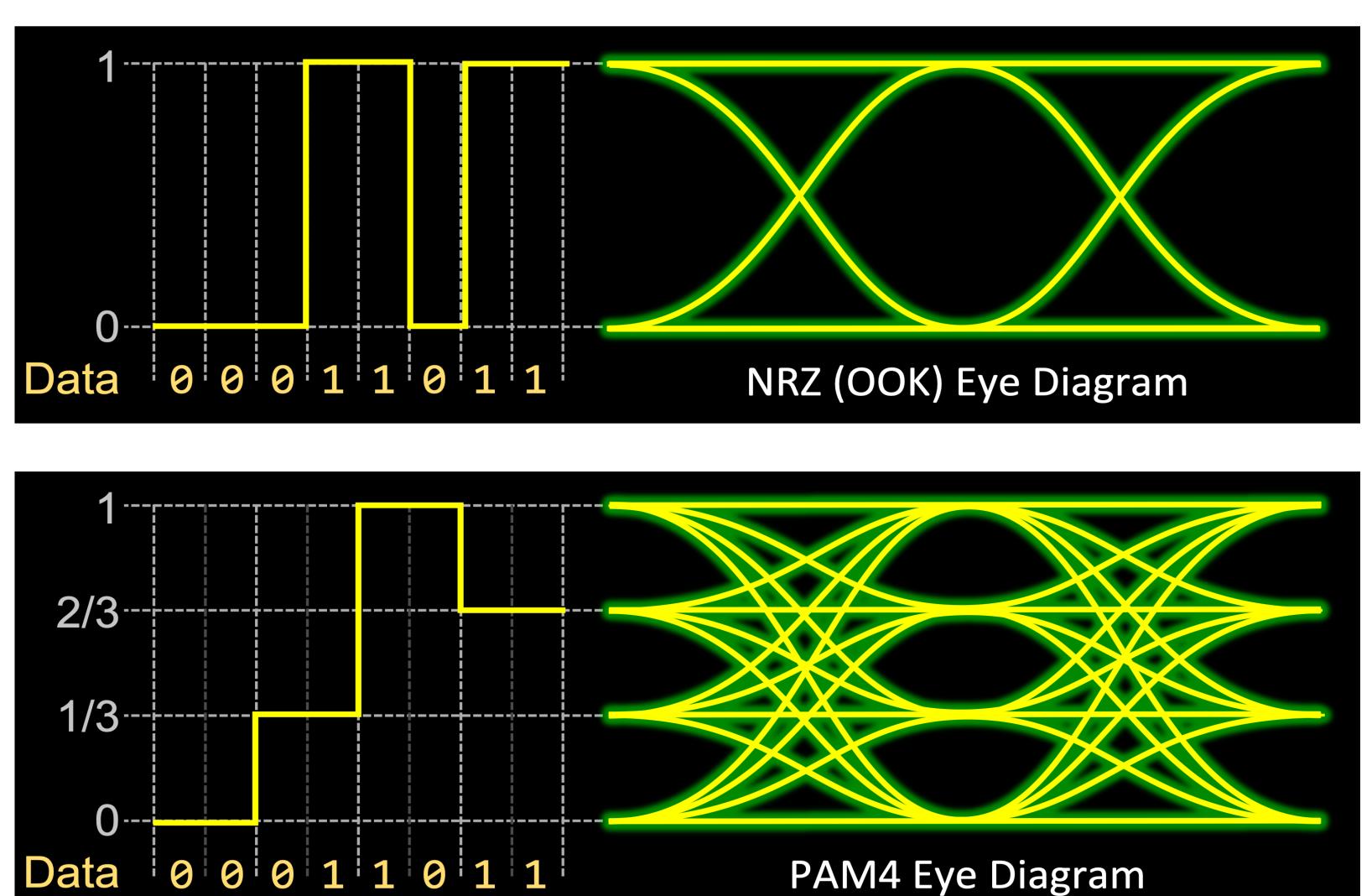
PAM4 modulation is used in the electrical and optical interfaces to improve total bus bandwidth.



As bit rates grow faster, the physical bits get smaller, carry less energy and face the switching and detection limits of electronics and optics, creating reach and error challenges for simple OOK techniques, such as NRZ.

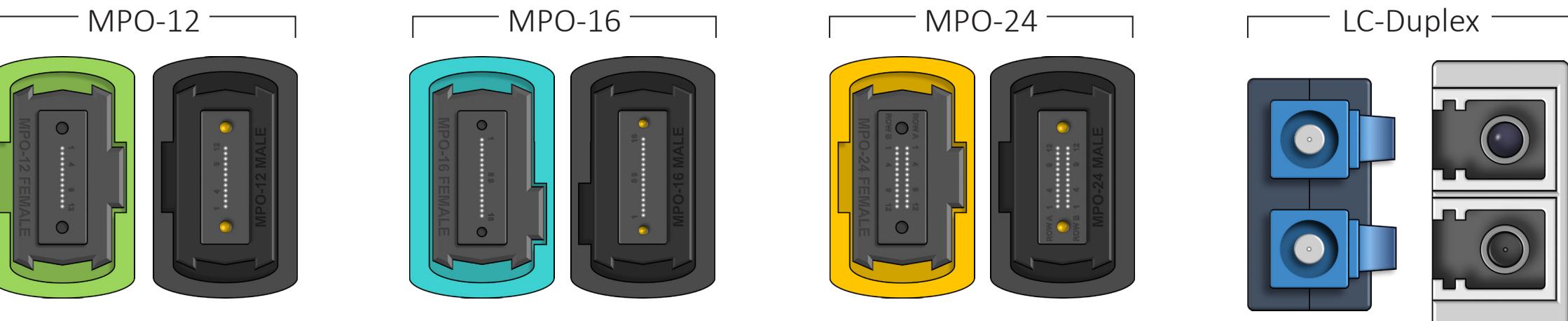
Although there is a 40 Gbps version of NRZ, 28 Gbps is now considered a safe limit for reliable electrical and optical transmission. Multiple electrical and optical lanes are used to increase transceivers' data rates to 100 Gbps (either multi-fiber or single-fiber WDM).

To break the 200 and 400 Gbps barrier an amplitude modulation scheme was introduced, PAM4, reducing the 56 Gbps lane rate to 28 Gbaud.

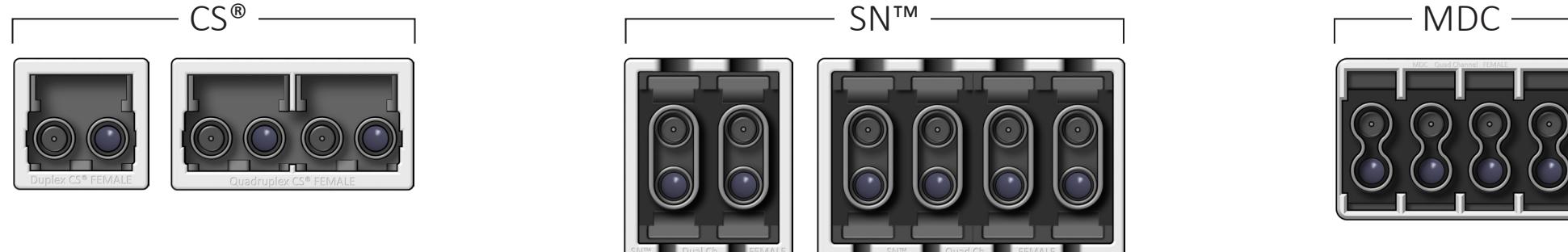


Optical Connectors & Cables

Common Fiber Optics Connectors (as of 2020)



Newly Approved Duplex and Quadruplex Fiber Optics Connectors (2019)



Standard Fiber Optics Cable Color Code (Based on TIA-492/598C)*

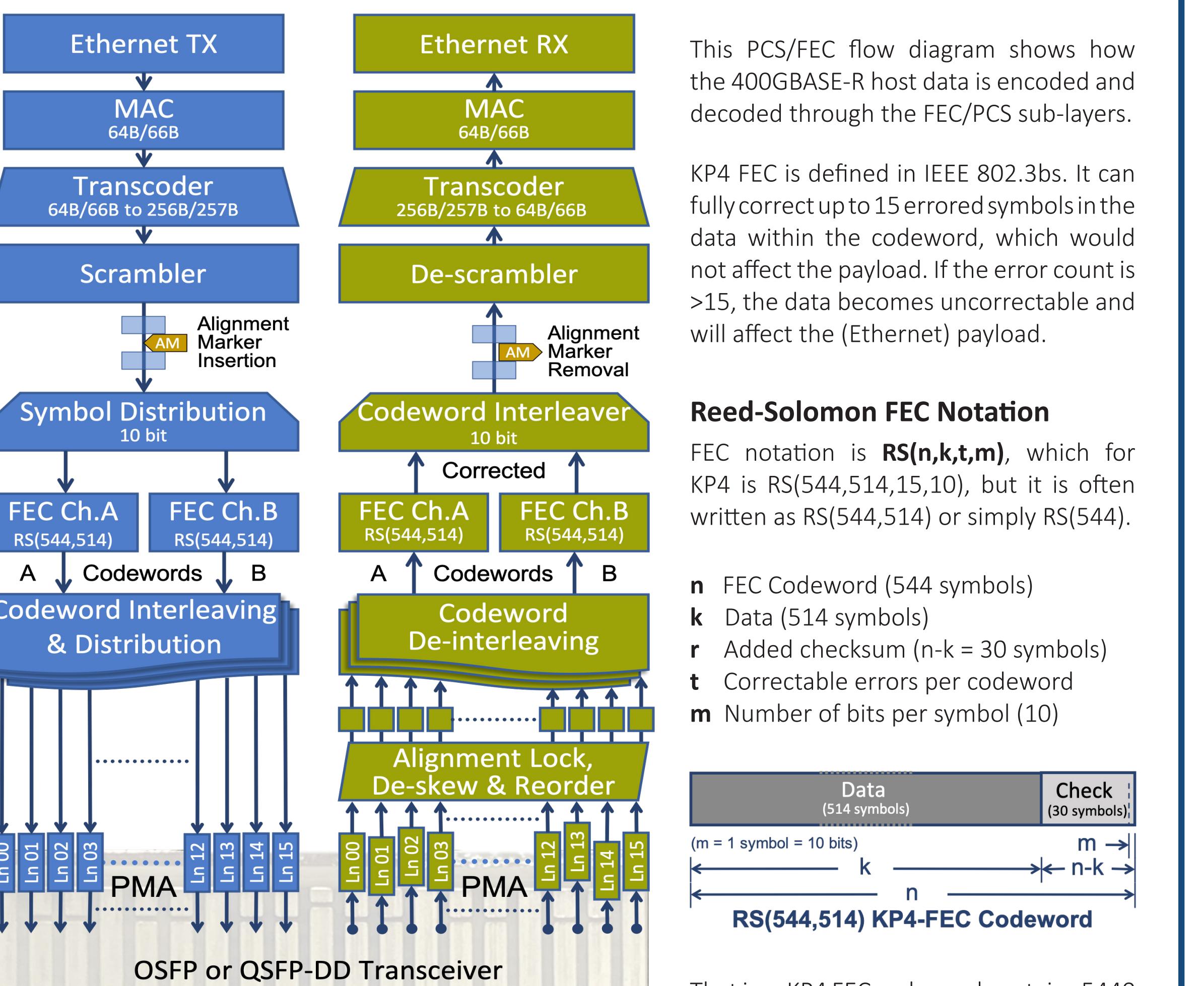
Type	Mode	Core/Cladding	Jacket	Connector	Comment
OM1	MMF	62.5/125 µm	Orange	Beige	LED multi-modal applications
OM2	MMF	50/125 µm	Orange	Black	LED multi-modal applications
OM3	MMF	50/125 µm	Aqua	Aqua	850 nm VCSEL optimized
OM4	MMF	50/125 µm	Aqua	Aqua	850 nm VCSEL optimized
OM4+	MMF	50/125 µm	Violet	Violet	850 nm VCSEL optimized
OM5	MMF	50/125 µm	Lime Green	Lime Green	953 nm VCSEL optimized
OS1, OS2	SMF	9/125 µm	Yellow	Blue	Green connector for APC

*Actual commercial colors may vary

400G KP4 Forward Error Correction (FEC)

Pre & Post FEC Errors

High speed Ethernet interfaces are inherently prone to errors, as they push the limits of electronics, optics and physical mediums. They all require error correction to be able to deliver error-free payloads end-to-end. KP4-FEC can correct up to 15 symbol errors within a codeword (correctable errors). If there are >15 errors within a codeword, then the user data (payload) is affected (uncorrectable or pos-FEC errors). Since pre-FEC errors will occur, link quality and performance testing focuses on lower symbol error distribution (symbol errors per codeword statistics) and on any post-FEC errors that affect the payload.



400G Interfaces

IEEE® 802.3bs 400GBASE-R

The 400G Ethernet interfaces (PHY or PMD) naming structure follow an industry standard notation, but new MSA variants continue to be defined. Recommended pull-tab colors may vary.

PMD	Optic. Interface	Mode/nm	TX+RX	Connector	Reach	Typ.	Tab ^{OSFP/QSFP}
SR16	16x 25G NRZ	MMF/850	32 (1λ)	MPO-32	100 m	/	/
SR8	8x 50G PAM4	MMF/850	16 (1λ)	MPO-16	100 m	■/■	■/■
FR8	8x 50G PAM4	SMF/1310	2 (8λ)	LC duplex	2 km	■■/■■	■■/■■
LR8	8x 50G PAM4	SMF/1310	2 (8λ)	LC duplex	10 km	■■■■/■■■■	■■■■/■■■■
SR4	4x 100G PAM4	SMF/850	8 (1λ)	MPO-12	100 m	■■■■/■■■■	■■■■/■■■■
DR4	4x 100G PAM4	SMF/1310	8 (1λ)	MPO-12	500 m	■■■■/■■■■	■■■■/■■■■
FR4	4x 100G PAM4	SMF/1310	2 (4λ)	LC duplex	2 km	■■■■/■■■■	■■■■/■■■■
LR4	4x 100G PAM4	SMF/1310	2 (4λ)	LC duplex	10 km	■■■■/■■■■	■■■■/■■■■

IEEE® 802.3cm/cn/ct

PMD	Optic. Interface	Mode/nm	TX+RX	Connector	Reach	Tab ^{OSFP/QSFP}
SR4.2	8x 50G PAM4	MMF/850/910	8 BiDi (2λ)	MPO-12	100 m	/
ER8	4x 100G PAM4	SMF/1310	2 (8λ)	LC duplex	40 km	■■/■■
ZR8*	4x 100G PAM4	SMF/1550	2 (1λ)	LC duplex	80 km	■■■■/■■■■

*Currently IEEE 400GBASE-ZR is not necessarily the same as OFIF's 400ZR or 400ZR+

Other Interfaces (MSAs)

Uses compatible PAM4 electrical bus. Created to lower cost, complexity and power requirements.

PMD	Optic. Interface	Mode/nm	TX+RX	Connector	Reach	Tab ^{OSFP/QSFP}
CWDM8	8x 50G NRZ	SMF	2 (8λ)	LC duplex	2-10 km	/

Passive & Active Direct Attach Cables

Used in local intra-connect (at switch and rack levels).

PMD	Optic. Interface	Mode/mn	TX+RX	Connector	Reach	Typ.	Tab ^{OSFP/QSFP}
CR8	Copper (DAC)	N/A	16 Twin-ax	N/A	3 m	■■/■■	■■/■■
CR4	Copper (DAC)	N/A	8 Twin-ax	N/A	3 m	■■/■■	■■/■■
AOC	Fiber	MMF/850	16 (1λ)	N/A	20 m	■■■■/■■■■	■■■■/■■■■

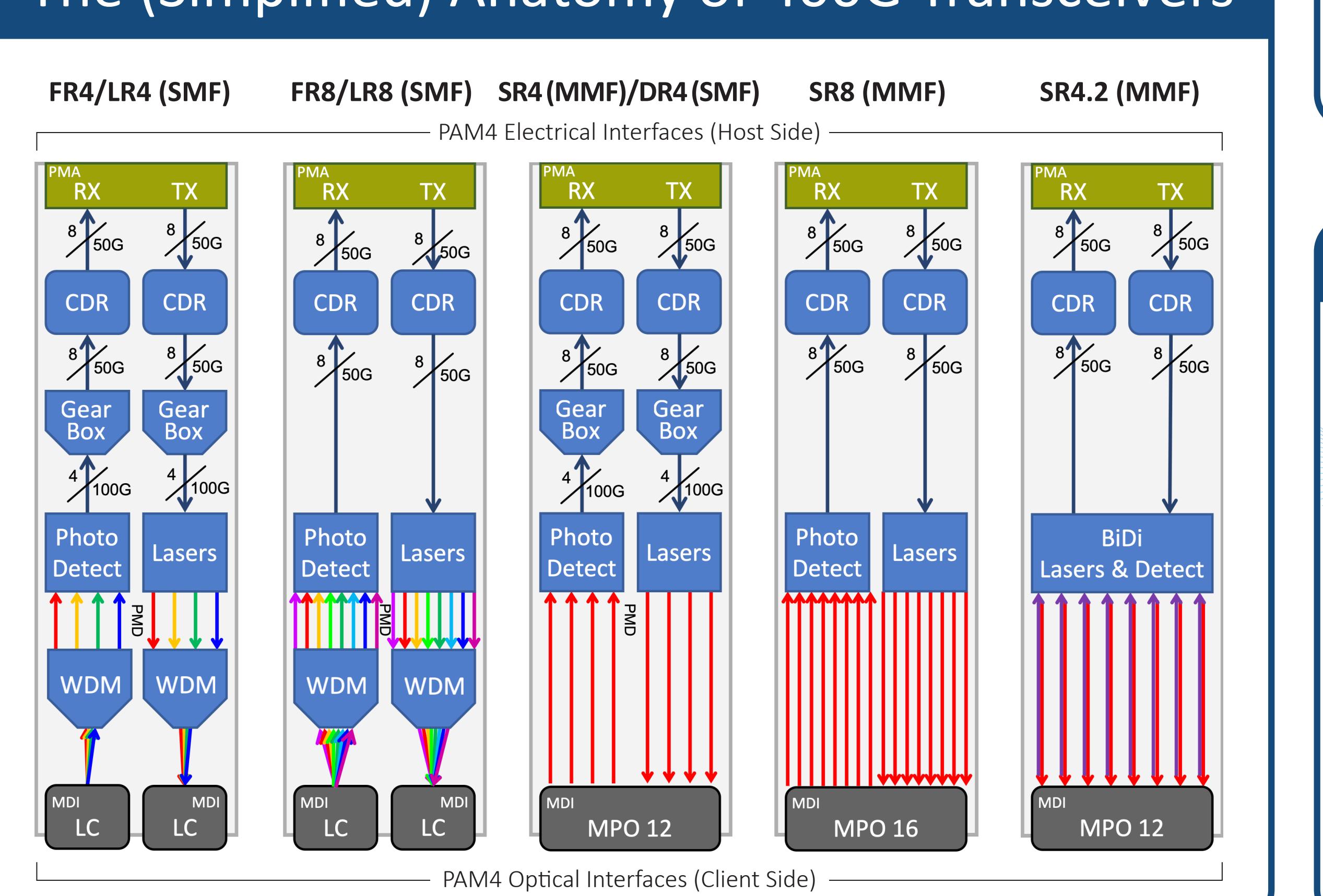
Optical Interworking Forum (OIF)

N	Data Rate (e.g. 400G)	TYPE	Modulation (e.g. BASEband)	X	Modular Bandwidth (MBW) requirement (ISO 11801)	Y	R = scrambled	Z	No. of optical lanes or copper pairs
N	■ Data Rate (e.g. 400G)	■ TYPE	■■■■ Modulation (e.g. BASEband)	C	■■■■ Copper (e.g. Coaxial)	S	■■■■ Short reach (e.g. 100 m)	D	■■■■ Datacenter (e.g. 500 m)
				F	■■■■ Fiber (e.g. 2 km)	L	■■■■ Long reach (e.g. 10 km)	E	■■■■ Extra long reach (e.g. 40 km)

OTHER RESOURCES

400G IEEE®802.3bs	www.ieee802.org
CWDM4 MSA	www.cwdm4-msa.org
Ethernet Alliance	www.ethernetalliance.org
ITU-T	https://www.itu.int/rec/T-REC
OIF	www.oiforum.com
OSPF MSA	www.ospmfa.org
QSFP-DD MSA	www.qsfp-dd.com
SFP / SFF	www.snia.org/sff/specifications
SFP-DD MSA	www.sfp-dd.com
SWDM Alliance & MSA	www.swdm.org

The (Simplified) Anatomy of 400G Transceivers



VeEX® 400G Test Solutions

- MPM-400AR: Dual QSFP-DD, QSFP56, SFP56
- MPM-400G: CFP8
- 400G Ethernet per IEEE 802.3bs
- Advanced KP4 FEC stress testing and analysis
- Physical, PCS/PHY, and Ethernet layer verification
- IC, transceiver, and board level testing
- Interoperability and product validation
- System level integration
- Multi-port traffic simulation and analysis
- Aggregation and load testing
- First portable 400G test solution supporting OSFP & QSFP56
- Native PAM4 OSFP and QSFP-DD interfaces for Best-in-Class signal integrity (no adapters required)
- All-in-one 1G-to-400G Ethernet test solution
- Advanced transceiver check
- Ideal for NEMs' SVT to FAEs assisting field demonstrations, evaluations, deployment, and troubleshooting
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