Multi-Core Fiber (MCF) Options for 400G-PAM4 Data Center Connectivity

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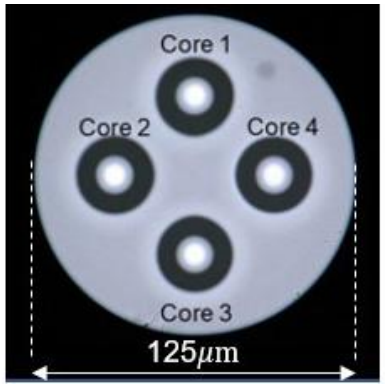
Large Scale AI Data Center Challenges

- Modern large AI Data Center Requirements:
  - Large scale with multi-building campus: Fiber connectivity reach > 2km
  - Massive fiber infra-structure:
    - Inside buildings ~ 20M x optical line channel (100Gbps or 200Gbps per channel)
    - Inter-buildings ~ 1M fibers x optical line channel
- Fiber Dispersion: CWDM start to hit limit << 2km at 400G-PAM4

Multi-Core Fiber (MCF) Types and Benefit of MCF



- There are many multi core fiber options
- We limit our discussion to 4-core “weakly coupled MCF”
  - Each core compatible with the conventional SMFs
  - 2x2 4 Cores Type to minimizing cross talk

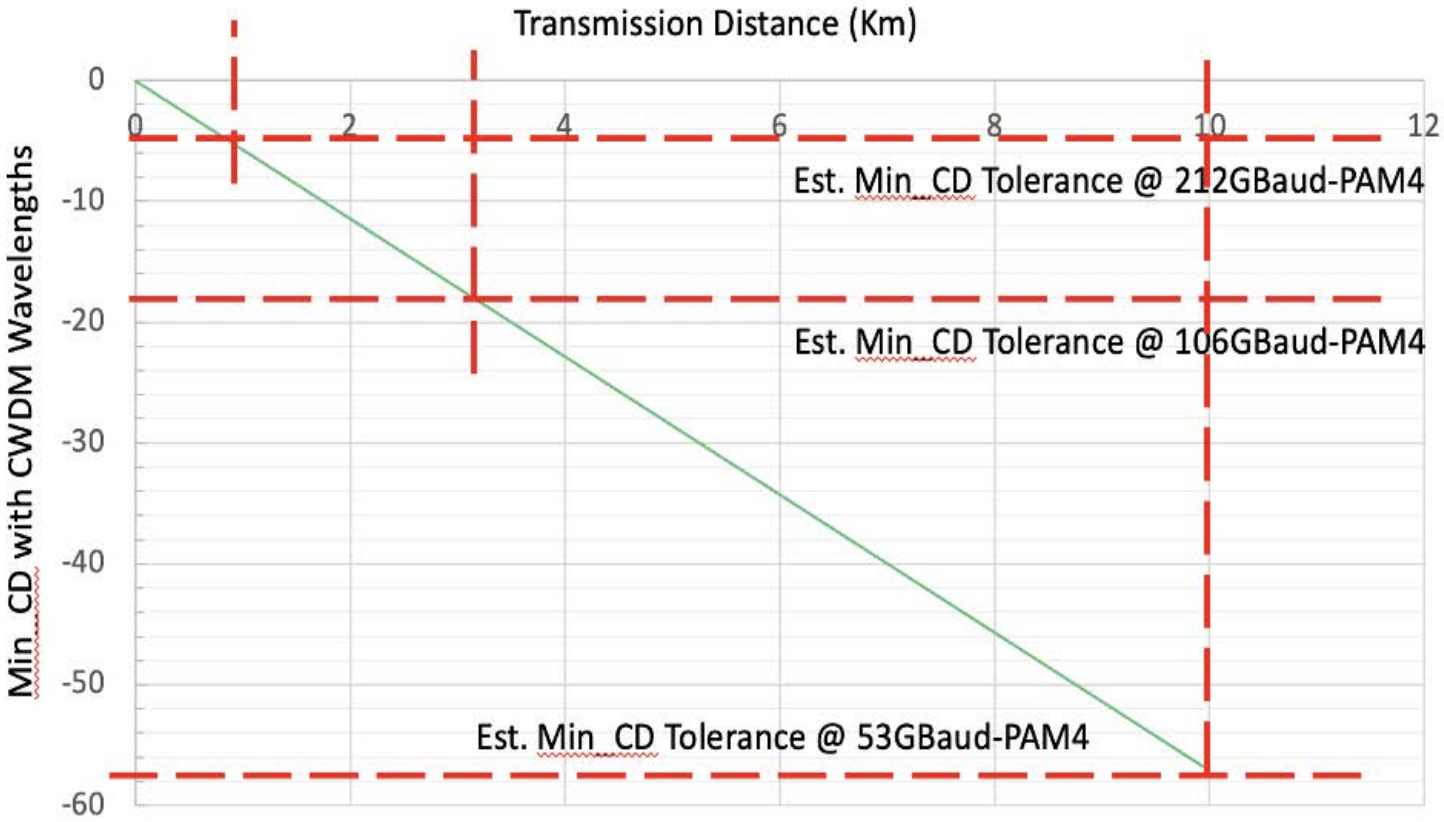
- Benefits:
  - Fiber count reduction by 4x
    - Reduce size and weight of optical fiber cables
    - Reduction of fiber handling complexity
  - Single wavelength option extend distance reach at high baud-rate with lower fiber chromatic dispersion vs. CWDM
  - Open options with higher optical coupling density for integrated photonics
    - Potentially 4x density increase per mm

MCF vs. PSMF and CWDM

	4-Core MCF@ 1310nm	PSMF@1310nm	CWDM@ 1271-1330nm
# of optical signal channel per fiber	4	1	4
# of fiber for Ref. TRx 800G-xR4	2	8	2
CD limited transmission @ 100G-PAM4	~10Km	~10km	~6-10km
CD Limited transmission @ 200G-PAM4	~10Km	~10km	~2.5km
CD Limited transmission @ 400G-PAM4	~2-3km	~2-3km	~ 600m

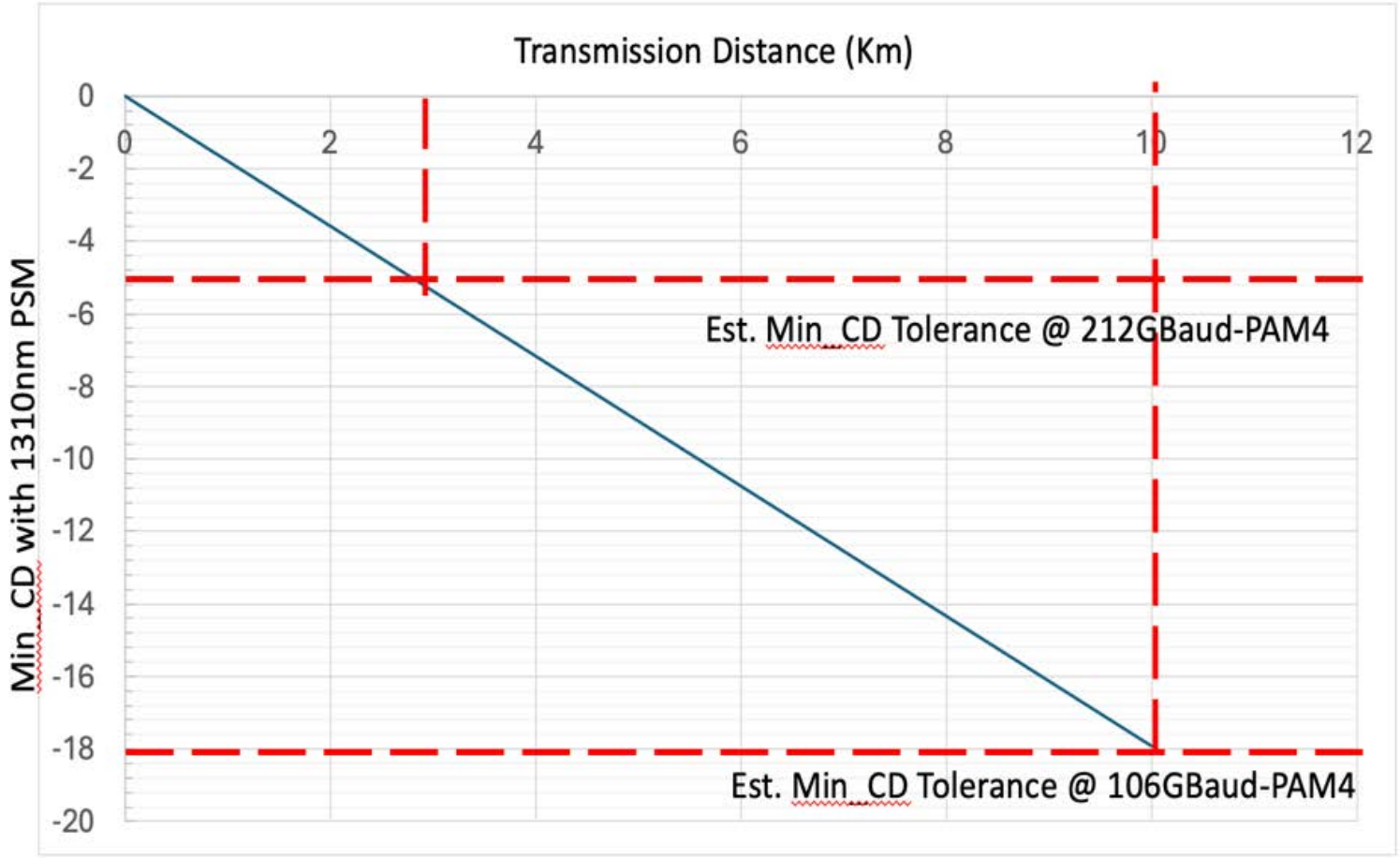
CWDM Limit for 200G-PAM4 and 400G-PAM4

- Fiber CD limiting reach for CWDM optics
  - ~10km for 100G-PAM4
  - ~3km for 200G-PAM4
  - <1km for 400G-PAM4



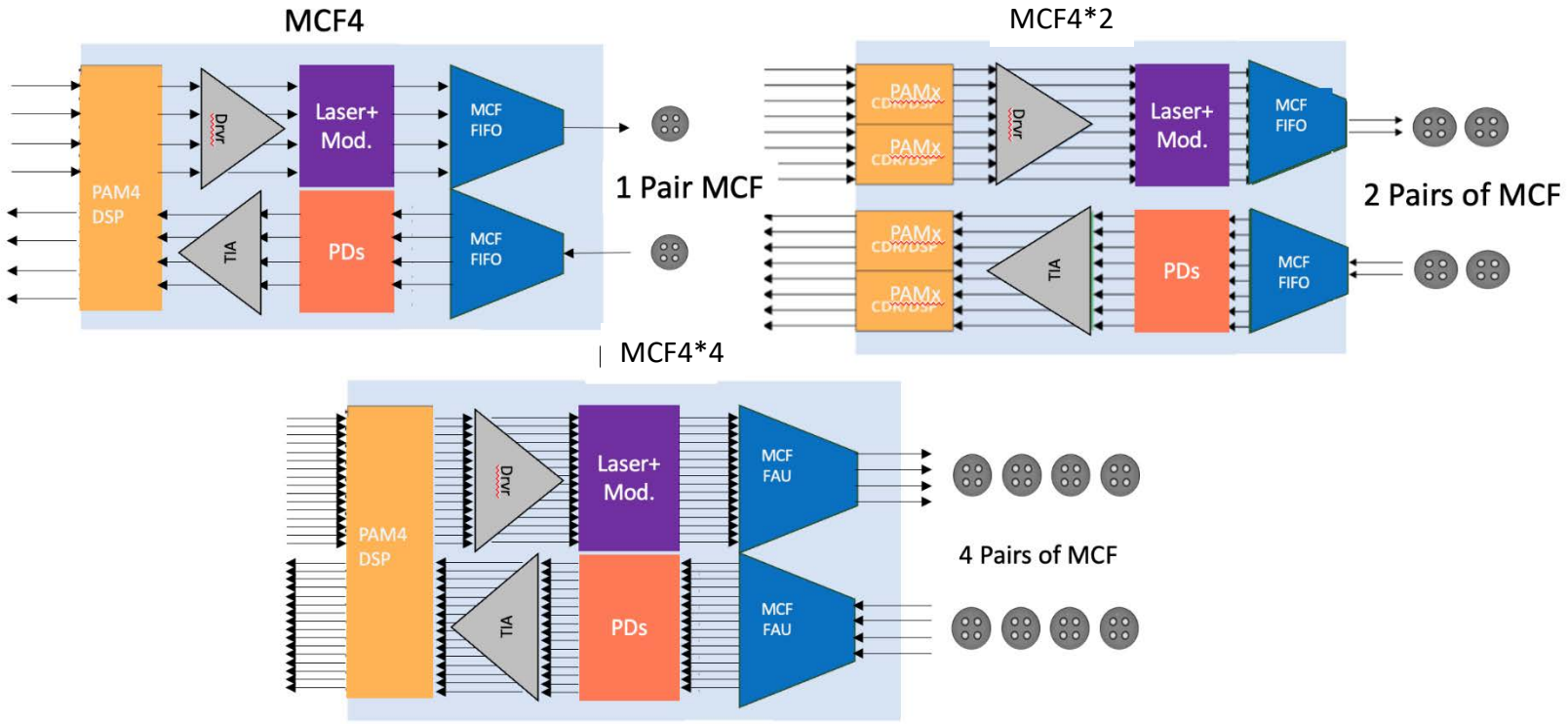
1310nm with MCF for 400G-PAM4

- 1310nm+/-6nm PSM with MCF can support much longer reach
  - ~10km @ 200G-PAM4
  - ~3km for 400G-PAM4



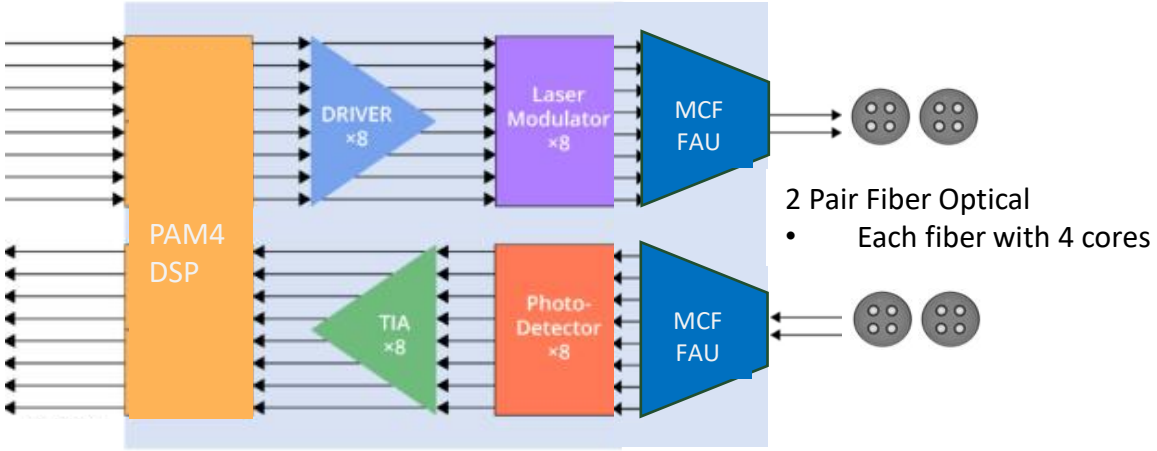
Proposed MCF Types for 400G-PAM4 PMD Considerations

	500m	2km
1.6T-MCF4	1.6T-MCF4-500m	1.6T-MCF4-2km
3.2T-MCF4*2	3.2T-MCF4*2-500m	3.2T-MCF4*2-2km
6.4T-MCF4*4	6.4T-MCF4*4-500m	6.4T-MCF4*4-2km



Example of A 800G-MCF4*2 Transceiver Module

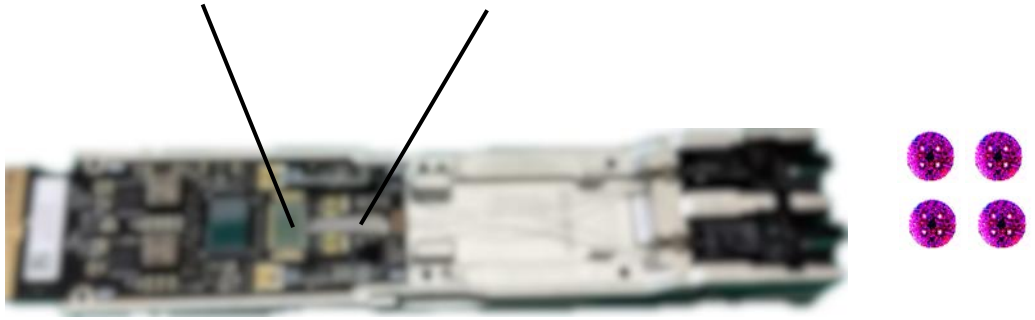
800G-MCF4*2 Transceiver



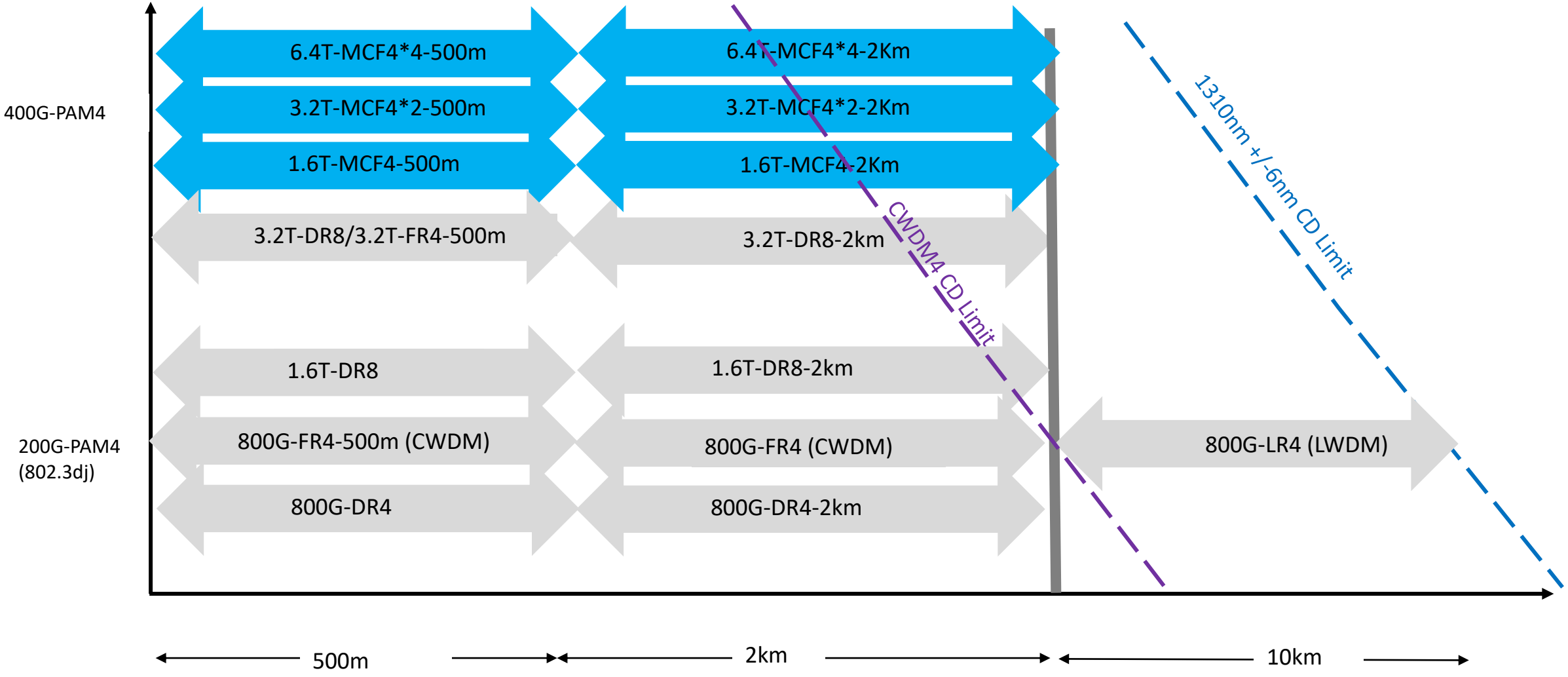
2 Pair Fiber Optical
- Each fiber with 4 cores

Silicon Photonics PIC

FAU with MCF Converter



Proposed MCF PMD Coverage



MCF Standardization Activities

Activities in ITU-T SG15

- **Work Programme: Optical Fibre, Cable, and Components for Space Division Multiplexing Transmission**
  - 01/2020: Started discussion to clarify the SDM technical maturity as a baseline for SDM fibre standardization.
  - 09/2022: Published Technical Report, GSTR-SDM. [https://www.itu.int/pub/T-TUT-HOME-2022-1]
- **Work Programme: Roadmap for SDM optical fibres concerning the development of G.65x series Recommendations** [https://www.itu.int/ITU-T/workprog/wp_item.aspx?isn=21559]
  - 11/2023: Started discussion to provide the roadmap of SDM fibre standardization
  - 2025: Plan to publish ITU-T Supplement. Determination on developing new MCF Recommendations will follow.

Activities in IEC TC86

- Continuously communicating with ITU-T for harmonization.
- Generally, IEC creates fibre test method standards,
  ITU-T develops fibre recommendations referring the IEC standards, and then
  IEC incorporates the ITU-T fibre recommendations into the IEC fibre product specifications.

WC-MCF Challenges to be investigated and resolved

- System vendors will have to take into account penalties associated with crosstalk in their link designs
  - There is not yet a standard for measuring crosstalk and there remain several proposed methods which are not yet agreed in standards
  - Crosstalk also must be analyzed in deployed cable form as it will be different from fiber on a reel in a lab

- For Polarization Mode Dispersion there is not a normative standard for short lengths, but there is some informative guidance.
  - MCF cabled fiber PMD is expected to be higher for a multicore cabled fiber than single core cabled fiber due to the added inherent stresses.

- If CWDM technology is ever desired to be used for 400 Gbps per lane at lengths up to 2 to 3km, the zero dispersion range and slope must be tighter than current standards.
  - This may pose a challenge to the fiber vendors as they will have to be able to select cores for this parameter prior to putting those cores into a blank, if that is practical. If not practical, then yield issues could be a problem.

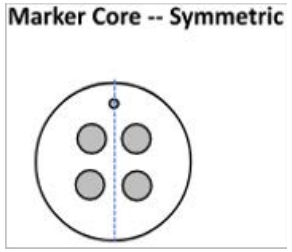
ITU-T SG15 Updates from the March 2025 Plenary

On Friday March 28 at the closing plenary:

- ITU-T is expected to approve the SDM Supplement for agreement
- ITU-T is expected to approve a new work item to begin a WC-MCF fiber standard for submarine applications
- ITU-T is expected to approve sending a liaison to IEEE 802.3 asking for the requirements for MCF links for short datacenter links

Recommendation for Data Center Focused MCF Spec.

Parameter - Applies to each core, unless stated otherwise	Specification	Reference Test Method / Comment
Attenuation (dB/km) - Cabled Fiber @ 1310nm	<0.4	IEC 60793-1-40
Point Discontinuity (dB) @1310nm	<0.1	IEC 60793-1-40
Optical Return Loss (dB) – absolute value @ all Points	≥ 60	TIA FOTP 8
Cable Cutoff Wavelength (nm)	≤ 1260	IEC 60793-1-44
Mode Field Diameter (µm) - Nominal Value @ 1310nm	Nominal 8.6-9.2; Tolerance: ± 0.4	IEC 60793-1-45
Zero Dispersion Wavelength – l_o (nm)	1300 to 1324	G.657 compliant
Zero Dispersion Slope – S_o (ps/(nm^2·km))	$0.073 \leq S_o \leq 0.092$	G.657 compliant
PMD - Cabled Fiber, individual fiber core (ps/√km)	≤ 0.4	FOTP-113
Crosstalk (unidirectional transmission) [dB at 1km] (1310nm)	≤ -40	
Crosstalk (bidirectional transmission) [dB at 1km] (1310nm)	≤ -40	
Fiber Geometry - 4 cores in 2x2 square array		
Core Radius	28.3 ± 1 µm	
Core Pitch	40 ± 1 µm	
Core Position Error	≤ 1 µm	
Marker Core Feature	Symmetric as shown	
Cladding Diameter	125.0 ± 1.0 µm	IEC 60793-1-20
Coating Diameter (Colored)	180 µm to 220 µm	IEC 60793-2-50:2018
Fiber Curl	≥ 4.0 m	IEC 60793-1-34
Strength		
Minumum Strength (by proof test) (kpsi)	≥ 100	IEC 60793-1-30 (FOTP-31)



Summary

- Large AI DC face challenges for massive fiber infrastructure and fiber dispersion limit
- MCF is promising technology solutions
- Proposed MCF as new PMD options for IEEE 802.3 future standards with 400G-PAM4 optics
  - Further proposed a few PMDs for considerations for future IEEE PMDs
- Recommend IEEE 802.3 consider a data center focused MCF project
  - MCF spec. may be considered as part of IEEE spec.
  - PMD for IEEE project shall be based on IEEE MCF spec.

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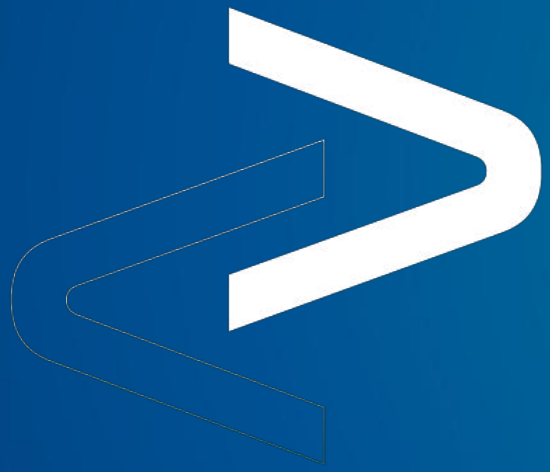

THANK YOU