# SDM4 Multicore Fiber MSA Technical Specifications

## Version 1.0

### Sept. 17, 2026

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# 1. General

This Multi-Source Agreement (MSA) defines a four-core multicore fiber (MCF) with a square-lattice 2×2 core arrangement for short-reach optical links operated in the O-band (SDM4 MCF). The specifications herein are intended to promote multi-vendor interoperability for SDM4 MCF used across diverse environments, including but not limited to data centers and campus networks, and other short-reach interconnect applications. The defined MCF is suitable for O-band optical links irrespective of modulation format (intensity-modulation/direct-detection or coherent). Examples of applicable interfaces include IEEE 802.3 DR/FR/LR types and other O-band implementations; transceiver specifications themselves are out of scope of this MSA.

# 2. Terms and Definitions

This section provides terms and definitions specific for multicore fibers.

Unless otherwise stated in this document, and where applicable, the terms, definitions, and standard measurement methods specified for single-mode optical fiber (SMF) in the documents listed below shall apply to, or be adapted for, SDM4 MCF. A suitable alternative (non-IEC) test method may be used, provided that the method reliably demonstrates conformance with the Specifications. Future MCF-specific standards, once established, should take precedence over SMF standards referenced herein.

IEC 60793-1-20, Optical fibres - Part 1-20: Measurement methods and test procedures - Fibre geometry
IEC 60793-1-21, Optical fibres - Part 1-21: Measurement methods and test procedures - Coating geometry
IEC 60793-1-30, Optical fibres – Part 1-30: Measurement methods and test procedures – Fibre proof test
IEC 60793-1-34, Optical fibres - Part 1-34: Measurement methods and test procedures - Fibre curl
IEC 60793-1-40, Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation
IEC 60793-1-42, Optical fibres – Part 1-42: Measurement methods and test procedures – Chromatic dispersion
IEC 60793-1-44, Optical fibres – Part 1-44: Measurement methods and test procedures – Cut-off wavelength
IEC 60793-1-45, Optical fibres – Part 1-45: Measurement methods and test procedures – Mode field diameter
IEC 60793-1-46, Optical fibres – Part 1-46: Measurement methods and test procedures – Point discontinuities
IEC 60793-1-48, Optical fibres – Part 1-48: Measurement methods and test procedures – Polarization mode dispersion
(latest editions at the time of publication)

## 2.1. Fiber geometry

Figure 2.1-1 shows a schematic of the geometrical parameters specific for multicore fibers. The parameters are defined below as follows.

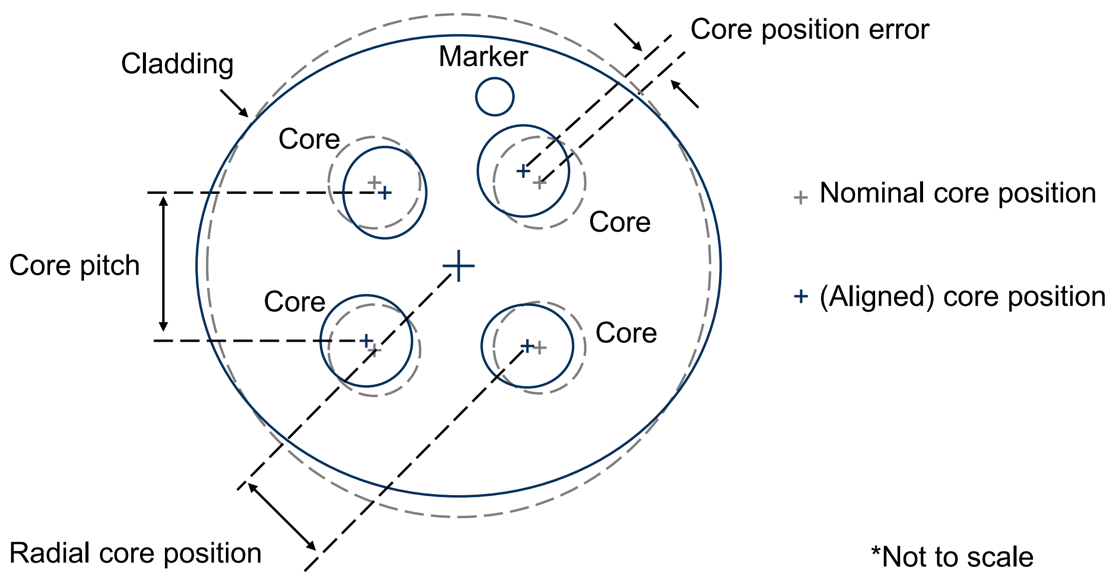


Figure 2.1-1: Schematic illustration of the geometric parameters of a multicore fiber. Solid circles indicate the actual outlines of the cores, the cladding, and the marker, whereas dashed circles indicate the nominal outlines.

**Nominal core position**: the nominal (x, y) coordinates of each core center in the reference coordinate system whose origin is the cladding center.

**Radial core position**: the distance from each core center to the cladding center

**Core pitch**: the center-to-center distance between adjacent cores.

**Core position error**: the deviation of each core's actual position from its nominal position in an MCF.

**Procedure for calculating core position error**:

1. Obtain the coordinates of the cladding center and each core center from a captured cross-sectional image of the fiber.

2. Translate the measured coordinates so that the cladding center coincides with the origin (0,0) of the reference coordinate system.

3. Rotate the measured coordinates about the origin by an angle $\theta$ to minimize the evaluation function $E(\theta)$, calculated from the differences ($\Delta x_i(\theta)$, $\Delta y_i(\theta)$) between rotated measured core positions ( $x_i(\theta)$, $y_i(\theta)$ ) and their nominal positions. $E(\theta)$ is defined as

$$E(\theta) = \sum_{i=1}^{4} \delta_i{}^n(\theta) \qquad (2.1\text{-}1)$$

$$\delta_i(\theta) = \sqrt{\Delta x_i(\theta)^2 + \Delta y_i(\theta)^2} \qquad (2.1\text{--}2)$$

where $n$ = 2 or 4.

4. The coordinates ( $x_i(\theta_{\min})$, $y_i(\theta_{\min})$ ) represents the **(aligned) core position** ("actual core position") and $\delta_i(\theta_{\min})$ represents the core position error of core $i$ at $\theta_{\min}$ that minimizes $E(\theta)$:

$$\theta_{\min} = \operatorname{argmin} E(\theta) \qquad (2.1\text{-}3)$$

While both $n$ = 2 and 4 are acceptable, the choice of $n$ is not restricted to these values; other exponents may be applied to accommodate future requirements or specific evaluation criteria. $E(\theta)$ with $n$ = 2 is used because it is based on the least-squares method on core position errors. $E(\theta)$ with $n$ = 4 is used because it is based on the least-squares method on the power of core position errors, which are proportional to connection losses.

## 2.2. Optical properties

### 2.2.1.Individual core properties

Individual core properties—such as attenuation, point discontinuities, cabled cut-off wavelength, mode field diameter (MFD), zero-dispersion wavelength and dispersion slope, and polarization mode dispersion (PMD)—are defined on a per-core basis. Launch and receive conditions shall be adapted accordingly. Consistent with the launch and receive conditions for SMF measurements, suitable launch and receive conditions shall be used to enable independent per-core measurements, with influence from other cores minimized and, where unavoidable, immaterial for conformance purposes.

### 2.2.2. Crosstalk (XT)

The (co-propagating) crosstalk (XT) between an "excited" core and a "disturbed" core is defined as the ratio of the transmitted optical power coupled into the disturbed core to that remaining in the excited core. For sufficiently long MCFs, the coupling into the disturbed core is typically subject to random perturbation along the fiber length. Under such conditions, the XT from the *i*-th core to the *j*-th core at wavelength $\lambda$, in an MCF of length $L$, can be defined as

$$XT_{ji}(\lambda, L) = \frac{\langle P_{ji}(\lambda,L)\rangle}{\langle P_{ii}(\lambda,L)\rangle} \tag{2.2.2-1}$$

where $P_{ji}(\lambda,L)$ denotes the output optical power from the *j*-th core when only the *i*-th core is excited at the wavelength $\lambda$, $P_{ii}(\lambda,L)$ is the optical power output from the *i*-th core. The bracket indicates the ensemble average.

In practical cases, the ensemble averages may be approximated with the averaging over optical frequency or optical wavelength. When $P_{ji}(\lambda, L) \ll P_{ii}(\lambda, L)$ holds, the XT can be measured by

$$XT_{ji}(\lambda, L) \cong \overline{\left(\frac{P_{ji}(\lambda,L)}{P_{ii}(\lambda,L)}\right)} \tag{2.2.2-2}$$

or

$$XT_{ji}(\lambda, L) \cong \frac{\overline{\left(P_{ji}(\lambda,L)\right)}}{\overline{\left(P_{ii}(\lambda,L)\right)}} \tag{2.2.2-3}$$

where the overline indicates an averaging process over wavelength, optical frequency, or time as appropriate. These are practical examples and do not restrict the use of other suitable approximations. A suitable measurement method to obtain values sufficiently equivalent to those defined in (2.2.2-1) may be used.

The XT should be presented on a decibel (dB) scale, as follows:

$$XT_{\mathrm{dB}}(\lambda, L)[\mathrm{dB}] = 10\log_{10} XT\,(\lambda, L) \tag{2.2.2-4}$$

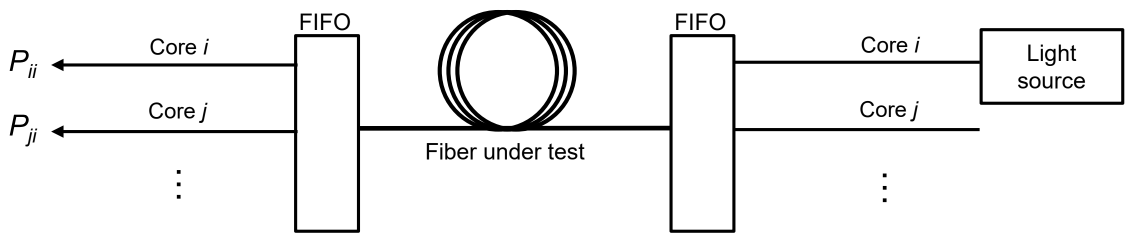
To launch the test light into and receive it from each core, the fan-in/fan-out (FIFO) devices may be used, or a SMF may be connected with an offset splice to align with the core position or other appropriate alignment technique to align with the core position while minimizing reflections and stray light into adjacent cores. When using the FIFO devices, the measured XT includes both the XT of the MCF and the XT within the FIFO devices. In some cases, the influence of FIFO XT should be considered, especially for short MCFs or when measuring XT between diagonal cores, as the XT can be very low in these situations.

Core-dependent loss (CDL) arises from variations in fiber attenuation, and splice or connector losses associated with the fiber under test, launching/receiving fibers, and measurement equipment. In cases where FIFO is used, core-to-core loss variation within the FIFO also contribute to CDL. This leads to asymmetry in crosstalk (XT) such that $XT_{ji} \neq XT_{ij}$. In some cases, CDL correction should be considered. In order to eliminate the influence of CDL when reporting XT values, two methods are currently known and can be used. One method is to use the mean of the XT measured in both coupling directions (*i*→*j* and *j*→*i* between the same pair of cores; this does not involve reversing the measurement direction along the fiber length. See Figure 2.2.2-1), expressed as:

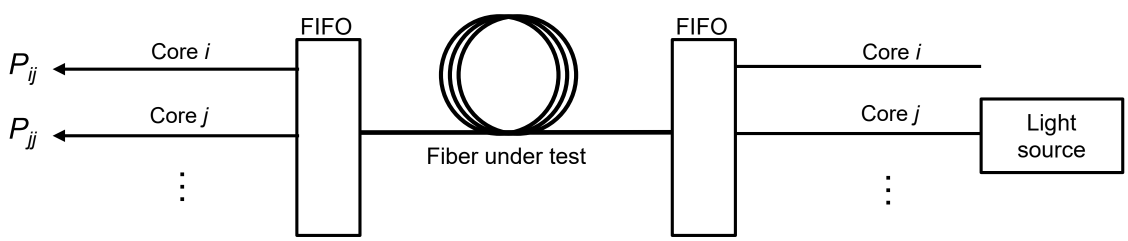
(Geometric mean in linear scale) $\overline{XT_{ji}(\lambda, L)} = \sqrt{XT_{ji}(\lambda, L)XT_{ij}(\lambda, L)}$, (2.2.2-5) or equivalently

(Arithmetic mean in dB scale) $$\overline{XT_{\mathrm{dB},ji}(\lambda, L)} = \frac{XT_{dB,ji}(\lambda,L)+XT_{dB,ij}(\lambda,L)}{2}. \qquad (2.2.2\text{-}6)$$

Another method is to de-embed known offsets of the measurement system from the measured XT values (i.e., divid in linear scale or subtract in dB).




(a) Setup configuration for measuring $XT_{ji} = \langle P_{ji}\rangle/\langle P_{ii}\rangle$




(b) Setup configuration for measuring $XT_{ij} = \langle P_{ij}\rangle/\langle P_{jj}\rangle$

Figure 2.2.2-1: Example of setup configurations for measuring (a) $XT_{ji}$ and (b) $XT_{ij}$.

For an MCF with longitudinally uniform structure and bending radius, it is possible to derive a XT per unit length or a power coupling coefficient between two adjacent cores, which is independent of the length of the fiber (XT grows linearly to fiber length):

$$h = \frac{\overline{XT_{ji}(\lambda,L)}}{L} \qquad (2.2.2\text{-}7)$$

If $h$ can be regarded as uniform along the fiber, the XT between two adjacent cores (the $i$-th core and the $j$-th core) in decibel scale can be expressed as (10 dB/decade growth):

$$10\log_{10}\overline{XT_{ji}(\lambda,z)} = 10\log_{10}\overline{XT_{ji}(\lambda,L)} + 10\log_{10}\frac{z}{L} \qquad (2.2.2\text{-}8)$$

and the XT between diagonal cores in a 2x2 MCF (the $i$-th core and the $k$-th core) as:

$$10\log_{10}\overline{XT_{ki}(\lambda,z)} = 10\log_{10}\overline{XT_{ki}(\lambda,L)} + 20\log_{10}\frac{z}{L} \qquad (2.2.2\text{-}9)$$

For an MCF with longitudinally non-uniform structure and/or bending radius, $h$ may not be rigorously uniform along the fiber. However, in many practical cases, assuming a uniform $h$ is sufficiently accurate to estimate the XT at a different fiber length. Therefore, (2.2.2-8) or (2.2.2-9) can be used to convert the XT value at $L$ to the XT value at $z$ = 1 km (specified in Section 3).

## 3. SDM4 MCF Specifications

SDM4 MCF shall meet the Specifications specified in Table 3-1.

### Table 3-1: SDM4 MCF Specifications

| Parameter - Applies to each core, unless stated otherwise | Specification | Comment |
|---|---|---|
| **Attenuation (dB/km) - Cabled Fiber** | | Applies to cabled fiber length of ≥1 km; values derived from shorter lengths have higher uncertainty. |
| 1310 nm | ≤ 0.4 | |
| **Point discontinuity (dB)** | | |
| 1310 nm | ≤ 0.1 | |
| **Cable cut-off wavelength (nm)** | ≤ 1260 | |
| **Mode field diameter (μm)** | | |
| 1310 nm | Nominal: 8.6-9.2<br>Tolerance: ± 0.4 | |
| **Zero dispersion wavelength, $\lambda_0$ (nm)** | 1300 to 1324 | |
| **Zero dispersion slope, $S_0$ (ps/(nm$^2$·km))** | $0.073 \leq S_o \leq 0.092$ | |
| **PMD - Cabled Fiber** | | |
| Individual fiber core PMD (ps/√km) | ≤ 0.4 | |
| **Crosstalk** | | |
| between adjacent cores (dB at 1km) at 1310 nm | ≤ -40 | |
| between diagonal cores (dB at 1km) at 1310 nm | ≤ -40 | |
| **Fiber geometry -** 4 cores | | See Fig. 3-1 for reference diagrams. |
| Nominal core positions | (20 μm, 20 μm),<br>(20 μm, -20 μm),<br>(-20 μm, 20 μm),<br>(-20 μm, -20 μm). | |
| Core position error | ≤ 1 μm | |
| Core pitch | 40 ± 1 μm | |
| Radial core position | 28 ± 1 μm | Based on the nominal core positions and represents the integer-rounded value; it is not an independent nominal. |
| Marker core feature | Both symmetric and asymmetric marker configurations are acceptable. | |
| Cladding diameter | 125.0 ± 1.0 μm | |
| Coating diameter (Colored) | 180 μm to 220 μm | |
| **Fiber curl radius** | ≥ 2 m | |
| **Strength** | | |
| Proof test level | ≥ 0.69GPa<br>(≥ 100 kpsi) | |

Figure 3-1 shows schematic cross-sections of SDM4 MCFs. A SDM4 MCF may have either an asymmetric marker configuration (a) or a symmetric marker configuration (b). Both configurations are acceptable.

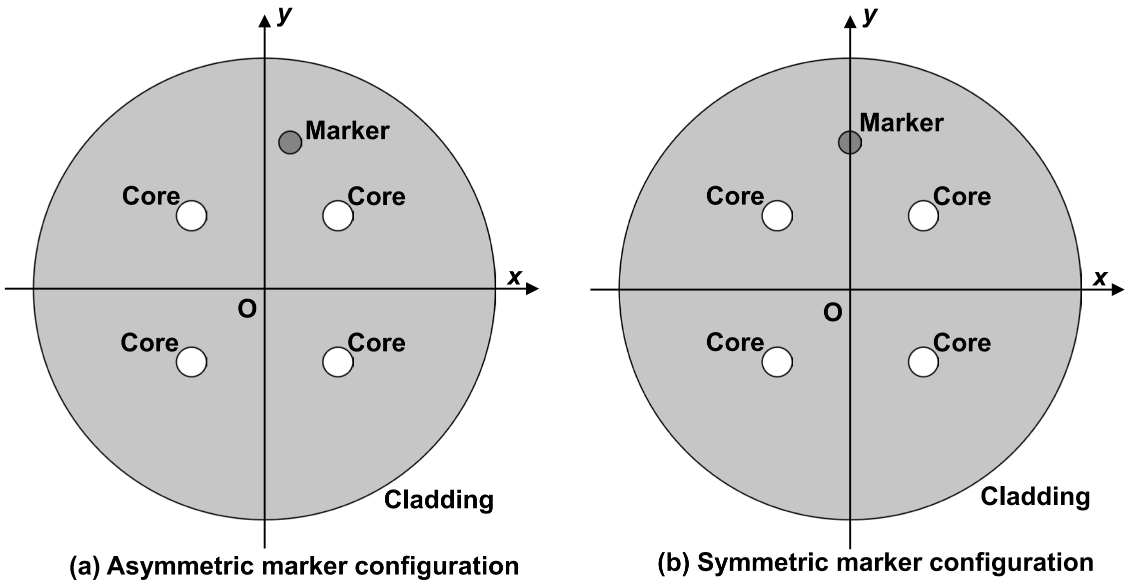



Figure 3-1: Schematic cross sections of SDM4 MCF

# 4. Appendix

## 4.1. Informative note: Core numbering

The selection of the core-numbering pattern may depend on the transmission scheme (e.g., unidirectional or bidirectional), connector configuration, transceiver configuration, and other system considerations. Accordingly, the core-numbering pattern may be defined, as appropriate, for the intended application.

Two major types of core-numbering patterns are shown in Fig. 4.1-1: (a,b) reversed-order and (c,d) pairwise-swap. The mapping between the opposite ends of the MCF is defined with respect to the symmetry axis (the y-axis in Fig. 4.1-1). This axis bisects the four-core array into two symmetric pairs; in the illustrations, the positive y direction denotes the orientation reference, which points toward the marker. In the reversed-order pattern, the sequence #1, #2, #3, #4 is reversed to #4, #3, #2, #1 ($i \rightarrow N + 1 - i$). In the pairwise-swap pattern, cores #1 and #2 are interchanged and cores #3 and #4 are interchanged between the opposite ends. With a symmetric marker configuration, core numbering may be defined at one end (e.g., the start-of-draw end) as shown in Figs. 4.1-1(b,d) and in reverse order at the other end. Alternatively, the same core numbering may be applied at both ends and treated as port numbering.

For installation, core numbering of bare MCFs is generally not essential. This is because rotational alignment can be managed by aligning the orientation references. The core array is the primary rotational datum, and the orientation reference provides coarse rotational guidance. Under these conditions, MCFs can be connected without enforcing core-number matching between mated MCFs. Fiber-level polarity management is not required. Marker positions need not coincide exactly between mated MCFs, and the mated fibers may use different marker configurations, as long as each configuration supports determination of the orientation reference (or symmetry axis) for rotational alignment. This principle applies to both connectorized assemblies and fusion splicing. For connectorized assemblies, rotational alignment is achieved by establishing a defined angular relationship between the connector key and the fiber's orientation reference during assembly. For fusion splicing, where no connector key is present, the same principle applies by aligning the orientation references of the two fibers based on their marker positions. Mixed longitudinal orientations of MCFs within a cable or connectorized assembly are acceptable and pose no operational issues when the alignment keys are rotationally aligned. In such cases, core or port numbers may be reassigned at the assembly level, irrespective of the original core numbering of the bare MCFs. If needed, identification of absolute core numbers can be supported with either asymmetric or symmetric marker configurations. With an asymmetric marker configuration, the MCF cross section eliminates symmetry, making the identification straightforward. With a symmetric marker configuration, the identification can be supported by supplementing with information about the fiber's longitudinal orientation (e.g. supplier-provided data).

Further details of this topic can be found in

[4.1-1] T. Hayashi, et al., "Uncoupled Multi-core Fiber Design for Practical Bidirectional Optical Communications," in OFC 2022, paper M1E.1. doi: 10.1364/OFC.2022.M1E.1.

[4.1-2] T. Hayashi, et al., "Proper Core Numbering and Clarification of Polarity Concepts for Polarity-Management-Free 4-Core Multicore Fiber Connections," in OECC 2024, doi: 10.1109/OECC54135.2024.10975554.

[4.1-3] T. Oda, et al., "Polarity-Insensitive Core Number Management of Multi-Core Fiber," in OECC/PSC 2025, doi: 10.23919/OECC/PSC62146.2025.11109279.

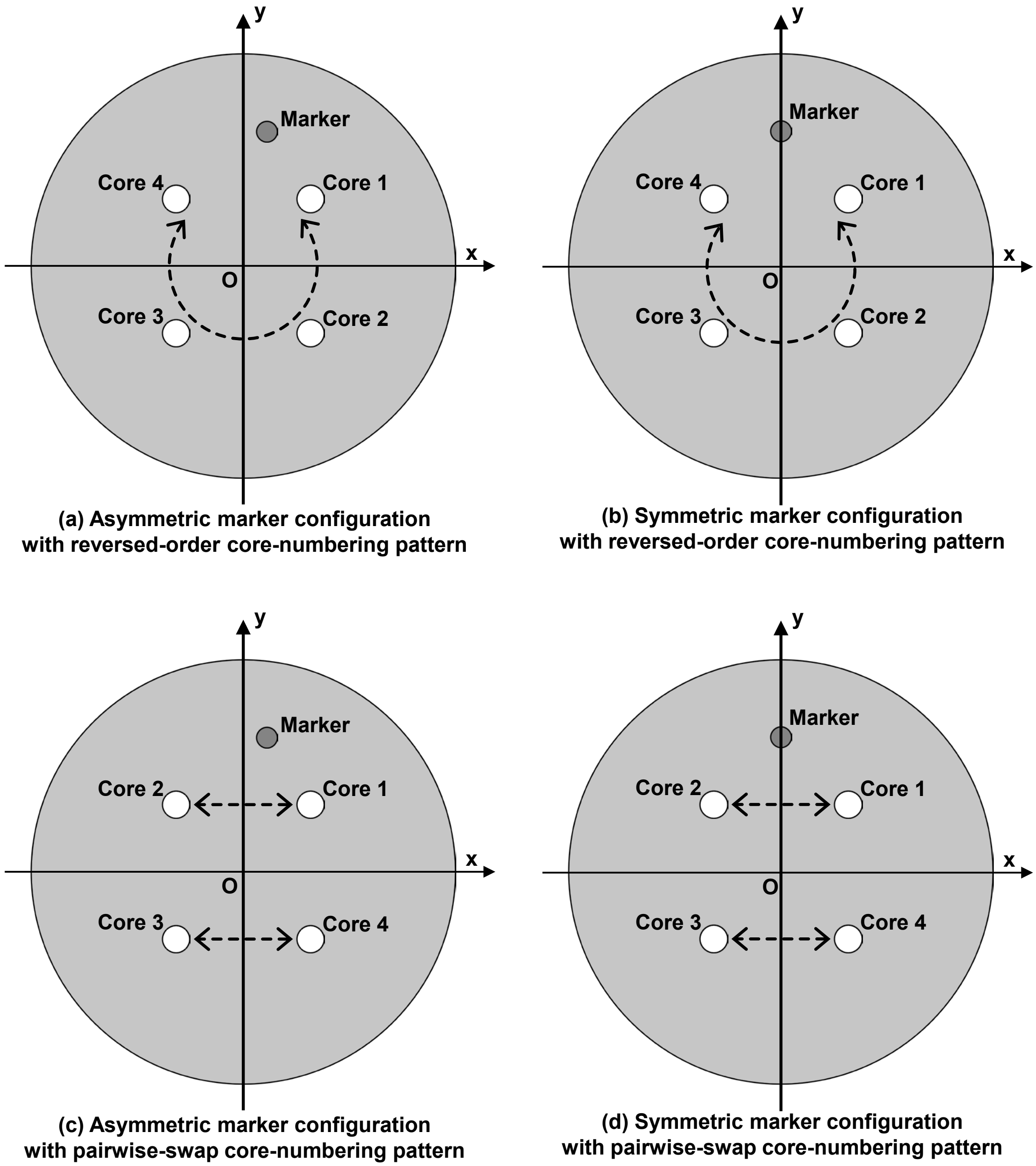



Figure 4.1-1: Two major core-numbering patterns for 4-core fiber with square-lattice core layout

## 4.2. Informative note: PMD requirement for short-reach optical links

This section describes technical background for the PMD specification in Table 3-1.

ITU-T G.652/G.657 specify PMD using the PMD link design value ($PMD_Q$). $PMD_Q$ is a statistical upper bound on the PMD coefficient of a link made of M concatenated cable sections, defined for an exceedance probability Q; in G.652.D, $PMD_Q$ is limited to 0.20 ps/√km for M=20 and Q=0.01% [4.2-1].

Short-reach data-center cabling is often a single continuous cable section (M=1). IEEE 802.3 public contributions therefore modeled a single-section PMD distribution consistent with $PMD_Q$=0.20 ps/√km at M=20, and derived an equivalent single-section upper PMD coefficient of about 0.43 ps/√km at a comparable (~$10^{-4}$ order) exceedance level [4.2-2].

IEEE 802.3 converts PMD to a cabling maximum DGD requirement by assuming Maxwellian DGD statistics and using a conservative ratio S = $DGD_{max}$/PMD = 3.75 (outage probability $8.21\times10^{-8}$) [4.2-3]:

$$\mathrm{DGD}_{\mathrm{max}} = S \cdot \mathrm{PMD}_{\mathrm{coeff}}\sqrt{L} \tag{4.2-1}$$

(e.g., $L$ = 10 km: 3.75·0.43·√10 ≈ 5 ps) [4.2-2][4.2-4].

Based on this established (informative) methodology, this MSA specifies a per-fiber-core PMD coefficient limit of 0.4 ps/√km (rounded from 0.43).

Table 4.2-1 summarizes the maximum operating distances and maximum DGDs in fiber optic cabling (channel) characteristics specified in IEEE 802.3, and corresponding maximum PMD coefficients. Except 500-m-reach DR links, the maximum PMD calculated using (4.2-1) are ~0.43 ps/√km (±0.01-ps/√km variations come from rounding in the maximum DGDs). Since 500-m-reach DR links tolerate the maximum PMD coefficient of 0.84 ps/√km, the PMD requirement for MCFs for ≤500-m-reach DR links may be relaxed upon agreement between the user and the supplier.

**Table 4.2-1: Fiber optic cabling (channel) characteristic requirements in SMF Ethernet standards.**

| | Maximum operating distance*1 | Maximum DGD [ps]*1 | Maximum PMD [ps]*2 | Maximum PMD coeff. [ps/√km]*2 | References |
|---|---|---|---|---|---|
| 100GBASE-DR | 500 m | 2.24 | 0.60 | 0.84 | IEEE Std 802.3-2022 |
| 100GBASE-FR1 | 2000 m | 2.3 | 0.61 | 0.43 | IEEE Std 802.3-2022 |
| 100GBASE-LR1 | 10000 m | 5 | 1.33 | 0.42 | IEEE Std 802.3-2022 |
| 400GBASE-DR4 | 500 m | 2.24 | 0.60 | 0.84 | IEEE Std 802.3-2022 |
| 400GBASE-FR4 | 2 km | 2.3 | 0.61 | 0.43 | IEEE Std 802.3-2022 |
| 400GBASE-LR4-6 | 6 km | 4 | 1.07 | 0.44 | IEEE Std 802.3-2022 |
| 800GBASE-DR8 | 500 m | 2.24 | 0.60 | 0.84 | IEEE Std 802.3df-2024 |
| 400GBASE-DR4-2 | 2000 m | 2.3 | 0.61 | 0.43 | IEEE Std 802.3df-2024 |
| 800GBASE-DR8-2 | 2000 m | 2.3 | 0.61 | 0.43 | IEEE Std 802.3df-2024 |

*1: Directly cited from references. *2: Calculated as (Maximum PMD) = (Maximum DGD) / 3.75, and (Maximum PMD coeff.) = (Maximum PMD) / √(Maximum operating distance in km).

References

[4.2-1] ITU-T Recommendation G.652 (08/2024), “Characteristics of a single-mode optical fibre and cable.”
[4.2-2] A. Anslow, “P802.3cu DGD penalty,” IEEE 802.3cu Task Force contribution, May 2019.
https://www.ieee802.org/3/cu/public/May19/anslow_3cu_01_0519.pdf
[4.2-3] A. Anslow, “Polarisation Mode Dispersion in 100GbE links,” IEEE 802.3ba contribution, Mar. 2008.
https://www.ieee802.org/3/ba/public/mar08/anslow_01_0308.pdf
[4.2-4] V. Ferretti, “An in-depth look at PMD and DGD scenarios for 50/100/200 Gbaud IMDD links,” IEEE P802.3dj Optics Ad Hoc, Aug. 29, 2024.
https://www.ieee802.org/3/dj/public/adhoc/optics/0824_OPTX/ferretti_3dj_optx_01b_240829.pdf