400G CWDM8
10 km Optical Interface
Technical Specifications
Revision 1.1

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Revision History

Revision	Date	Description
1.0	12/18/2017	Initial release
1.1	1/21/2018	Replaced PRBS31 pattern with SSPR, changed golden PLL BW to 4 MHz, removed SRS eye mask, added comment for SEC in SRS testing, added pull tab color

1. General

The companies that prepared this version of the specification acknowledge the work of the IEEE 802.3 standards efforts and the CWDM4 MSA. These CWDM8 Specifications are based on much of the work the IEEE standards body has developed for 400G industry standards as well as the CWDM4 MSA. This technical document has been created with inputs from several companies. This document is offered to transceiver users and suppliers as a basis for discussion and comment. However, it is not a warranted document, each transceiver supplier will have their own datasheet. If the user wishes to find a warranted document, they should consult the datasheet of the chosen transceiver supplier.

1.1. Scope

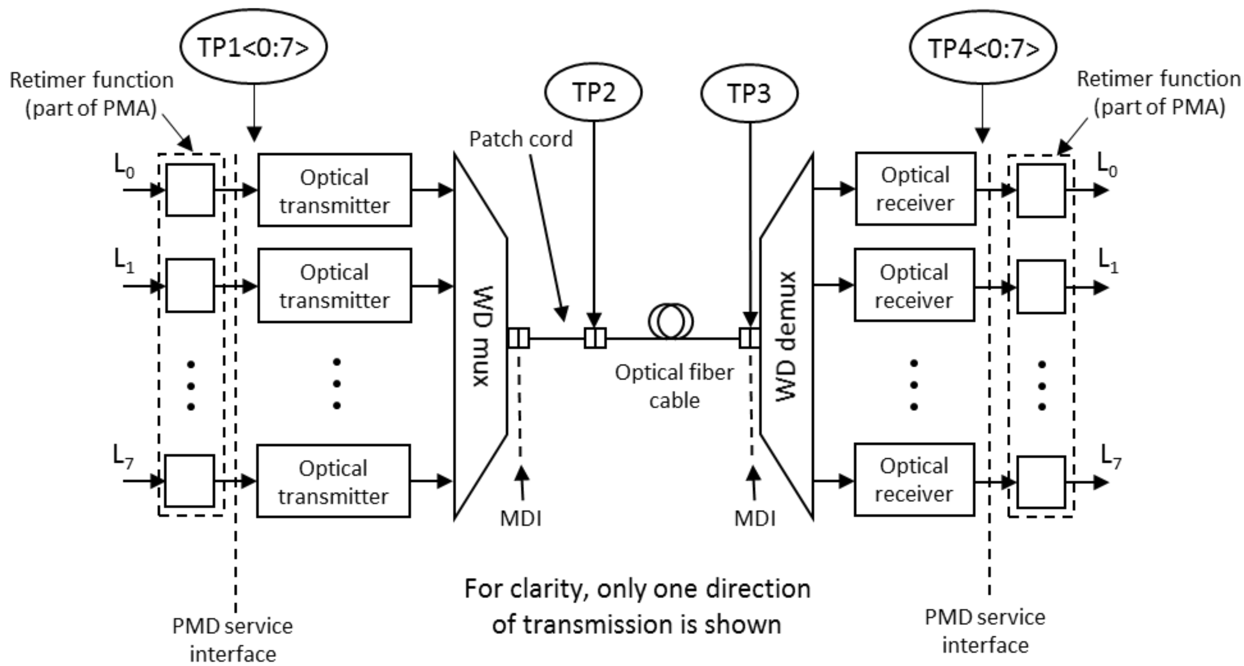
These technical specifications define an 8 x 50 Gb/s Coarse Wavelength Division Multiplexing (CWDM) optical interface for 400 Gb/s optical transceivers for Ethernet applications including 400 Gigabit Ethernet. Two optical transceivers implementing this interface can communicate over single mode fibers (SMF) of length from 2 meters up to 10 kilometers. The transceiver electrical interface is not specified in this document but can have, for example, 8 lanes in each direction with a nominal signaling rate of 53.125 Gb/s per lane.

Different form factors for the transceivers are possible. Common implementations at the time of this writing are expected to include QSFP-DD and OSFP pluggable optical transceivers as well as COBO on-board optical transceivers. Other form factors are possible and are not precluded by these specifications.

1.2. Reference Documents

IEEE 802.3bs
IEEE Std 802.3-2015
OIF-CEI-03.1 (http://www.oiforum.com)
OIF-CEI-56G specification family (http://www.oiforum.com)
QSFD-DD MSA (http://www.qsfp-dd.com/)
OSFP MSA (http://osfpmsa.org/)
ITU-T Recommendations G.652 and G.657

1.3. 400G CWDM8 Transceiver Block Diagram



WD = Wavelength division

NOTE – Specification of the retimer function is beyond the scope of this MSA.

Figure 1: Block diagram for 400G CWDM8 transmit and receive paths

1.4. Functional Description

CWDM8 optical transceivers comply with the requirements of this document and have the following common features: eight optical transmitters; eight optical receivers with signal detect; wavelength division multiplexer and demultiplexer; and a duplex optical connector for single mode fiber. The optical connector type is vendor specific and not defined in these specifications, but can include SC or LC types.

1.5. Hardware Signaling Pins

Hardware signaling pins are specified in the respective optical transceiver form factor MSAs.

1.6. Optical Transceiver Management Interface

The contents of the various ID registers in optical transceiver memory shall comply with the requirements of the optical transceiver MSAs, e.g. the QSFP-DD MSA or the OSFP MSA and the respective applicable standards.

1.7. High Speed Electrical Characteristics

The detailed high speed electrical characteristics are not defined by these specifications, and can be implemented in compliance with the IEEE 400GAUI-8 interface, OIF CEI-56G-VSR, or other appropriate IEEE, OIF, or other electrical interface standards.

1.8. FEC Requirements

The optical link is specified to operate at a bit error ratio (BER) of 2 x 10^{-4}. To support this optical interface specification, the host system is required to enable 400G RS(544,514) FEC in accordance with clause 119 of IEEE 802.3bs. The option to bypass the Clause 119 RS-FEC correction function is not supported.

1.9. Mechanical Dimensions

Mechanical dimensions are defined in the optical module form factor MSA specifications.

1.10. Operating Environment

All specified minimum and maximum parameter values shall be met when the host system maintains the operating case temperature and supply voltages within the optical module vendor specified operating ranges. All minimum and maximum limits apply over the operating life of the system.

1.11. Power Supplies and Power Dissipation

Optical transceiver vendors shall specify the optical module power supply requirements in accordance with the optical module MSA.

2. CWDM8 Optical Specifications

2.1. Optical Wavelengths

The wavelength range for each lane of the 400G CWDM8 optical transceiver is defined in Table 1. The center wavelengths are spaced at 20 nm.

Table 1: Wavelength Range

Lane	Center Wavelength	Wavelength Range
L_0	1271 nm	1264.5 to 1277.5 nm
L_1	1291 nm	1284.5 to 1297.5 nm
L_2	1311 nm	1304.5 to 1317.5 nm
L_3	1331 nm	1324.5 to 1337.5 nm
L_4	1351 nm	1344.5 to 1357.5 nm
L_5	1371 nm	1364.5 to 1377.5 nm
L_6	1391 nm	1384.5 to 1397.5 nm
L_7	1411 nm	1404.5 to 1417.5 nm

2.2. Optical Specifications

The operating range for a CWDM8 transceiver is defined in Table 2. A CWDM8 compliant PMD operates on single-mode fibers according to the specifications defined in Table 8 and characteristics in Table 9. A PMD that exceeds the required operating range while meeting all other optical specifications is considered compliant (e.g., operating at 15 km meets the operating range requirement of 2 m to 10 km).

Table 2: Operating range

Module type	Required operating range
400GE-CWDM8-10	2 m to 10 km

2.2.1. CWDM8 Transmitter Optical Specifications

The 400G CWDM8 transmitter shall meet the specifications defined in Table 3.

Table 3: 400G CWDM8 transmit characteristics

Description	Minimum	Maximum	Unit
Signaling rate, each lane	53.125 ± 100 ppm		Gbd
Modulation format	NRZ		
Wavelengths	1264.5 1284.5 1304.5 1324.5 1344.5 1364.5 1384.5 1404.5	1277.5 1297.5 1317.5 1337.5 1357.5 1377.5 1397.5 1417.5	nm
Side mode suppression ratio (SMSR)	30	-	dB
Total average launch power	-	8.5	dBm
Average launch power, each lane[a]	-5.5	2.5	dBm
Optical modulation amplitude (OMA), each lane[b]	-3	2.5	dBm
Launch power in OMA minus TDEC, each lane	-4	-	dBm
Difference in launch power between any two lanes (average and OMA)	-	4	dB

Transmitter dispersion and eye closure penalty (TDEC), each lane[c]	-	3	dB
Average launch power of OFF transmitter, each lane	-	-30	dBm
Extinction ratio	3.5	-	dB
Optical return loss tolerance	-	15.6	dB
Transmitter reflectance[d]	-	-26	dB

[a] The minimum requirement for average launch power, each lane is informative and not the principal indicator of signal strength. A transmitter with launch power below this value cannot be compliant; however, a value above this does not ensure compliance.

[b] Even if the TDEC < 1.0 dB, the minimum OMA must exceed the minimum OMA requirement.

[c] It is expected that a chirped transmitter will be required to meet this TDEC value for a 10km link.

[d] Transmitter reflectance is defined looking into the transmitter.

2.2.2. CWDM8 Receiver Optical Specifications

The CWDM4 receiver shall meet the specifications defined in Table 4.

Table 4: 400G CWDM8 receive characteristics

Description	Minimum	Maximum	Unit
Signaling rate, each lane	53.125 ± 100 ppm		Gbd
Wavelengths	1264.5 1284.5 1304.5 1324.5 1344.5 1364.5 1384.5 1404.5	1277.5 1297.5 1317.5 1337.5 1357.5 1377.5 1397.5 1417.5	nm
Damage threshold, each lane[a]	3.5	-	dBm
Average receive power, each lane[b]	-11.8	2.5	dBm
Receive power in OMA, each lane	-	2.5	dBm
Receiver reflectance	-	-26	dB
Receiver sensitivity (OMA), each lane at 2 x 10^{-4} BER[c]	-	-10.3	dBm
Stressed receiver sensitivity (OMA), each lane[d]	-	-7.3	dBm
Conditions of stressed receiver sensitivity test			
Stressed eye closure, each lane[e]	3		dB
Stressed eye J2 jitter, each lane[e]	0.33		UI
Stressed eye J4 jitter, each lane[e]	0.48		UI

[a] The receiver shall be able to tolerate, without damage, continuous exposure to a signal having this average power level

[b] The minimum requirement for average receive power, each lane is informative and not the principal indicator of signal strength. A received power below this value cannot be compliant; however, a value above this does not ensure compliance.

[c] Receiver sensitivity (OMA), each lane is a normative specification

[d] Measured with conformance test signal at TP3 (see 3.10) for BER = 2 x 10^{-4}

[e] Stressed eye closure penalty, stressed eye J2 jitter, and stressed eye J4 jitter are test conditions for measuring stressed receiver sensitivity. They are not characteristics of the receiver.

2.2.3. CWDM8 10 km Interface, Illustrative Link Power Budget

An illustrative power budget and penalties for CWDM4 are shown in Table 5.

Table 5: 400G CWDM8 illustrative power budget

Description	Value	Unit
Power budget (for max TDEC)	9.3	dB
Operating distance	10	km
Channel insertion loss[(a)]	6.3	dB
Maximum discrete reflectance[(b)]	-35	dB
Allocation for penalties (for max TDEC)	3	dB
Additional insertion loss allowed	0	dB

(a) Includes 0.2 dB MPI penalty
(b) Assumes 8 connectors in the link

3. Definition of Optical Parameters and Measurement Methods

3.1. Test Patterns for Optical Parameters

All optical measurements shall be made through a short patch cable, between 2 m and 5 m in length, unless otherwise specified.

Table 6: Patterns for optical parameter testing

Parameter	Pattern
Wavelength	SSPR
Side mode suppression ratio	SSPR
Average optical power	SSPR
Optical modulation amplitude (OMA)	Square wave
Transmitter dispersion and eye closure penalty (TDEC)[(a)]	SSPR
Extinction ratio	SSPR
Transmitter optical waveform	SSPR
Stressed receiver sensitivity	SSPR
Calibration of OMA for receiver tests	PRBS9
Vertical eye closure penalty calibration	SSPR

(a) Or RS-FEC encoded scrambled idle according to IEEE802.3bs Clause 119

3.1.1. Square Wave Pattern Definition

A pattern consisting of eight ones followed by an equal run of zeroes may be used as a square wave.

3.1.2. SSPR Pattern Definition

The SSPR pattern is defined as:

PRBS28	CID	PRBS28	PRBS28	$\overline{\text{PRBS28}}$	$\overline{\text{CID}}$	$\overline{\text{PRBS28}}$	$\overline{\text{PRBS28}}$
Seed=0080080	1, 72 x 0	Seed=FFFFFFF	Seed=0080080 Diff encoded	Seed=0080080	0, 72 x 1	Seed=FFFFFFF	Seed=0080080 Diff encoded
5437 bits	73 bits	5437 bits	5434 bits	5437 bits	73 bits	5437 bits	5434 bits

- Total length 32,762 bits
- All 2^28-1 PRBS28 sequences are generated using taps 25 and 28
- Block 1 is 5437 bits of PRBS28 seed=0x0080080 and begins with 8x0,1,11x0,1,12x0, 1
- Block2 is 1 followed by 72x0

- Block 3 is 5437 bits of PRBS28 seed=0xFFFFFFFF and begins 28x1,25x0,3x1,22x0
- Block 4 takes the same sequence as block 1 (omitting the last 3 bits) and codes it:
  - A zero is encoded as a change of output
  - A one is encoded as no change of output
  - The output before the first bit is assumed to have been a 0
  - This block begins 1010101001010101010110101010101011011010
- Blocks 5 to 8 are the inverse of 1 to 4

Under some circumstances (e.g. to accommodate the restrictions of some pieces of test equipment) it may be desirable to modify this short pattern to have a total length of 32,768 bits (2^15) rather than 32,762 bits. To make use of this option, the differentially encoded blocks (blocks 4 and 8) should be extended by 3 bits making these blocks 5437 bits long.

3.2. Skew and Skew Variation

Refer to IEEE Std 802.3bs Clause 122.3. CWDM8 MSA transceivers shall comply with the skew and skew variation limits of IEEE Std 802.3bs clause 122.3.1 and 122.3.2.

3.3. Wavelength

Measure per TIA/EIA-455-127-A or IEC 61280-1-3.

3.4. Average Optical Power

Measure using the methods given in IEC 61280-1-1 with channels not being measured turned off.

3.5. Optical Modulation Amplitude (OMA)

Refer to IEEE Std 802.3-2015 Clause 52.9.5. OMA is measured with a square wave (8 ones, 8 zeroes) test pattern. Each lane may be tested individually with all other lanes turned off, or by using an optical filter if the other lanes are active.

3.6. Transmitter Dispersion and Eye Closure Penalty (TDEC)

TDEC shall be as defined in IEEE Std 802.3-2015 Clause 95.8.5 with the exceptions that:

- The optical to electrical converter bandwidth shall not include the optical channel, which shall be included explicitly as shown in 3.6.1 below
- Each optical lane is tested individually using an optical filter to separate the lane under test from the others. The optical filter pass band ripple shall be limited to 0.5 dB peak-to-peak, and the isolation is chosen such that the ratio of the power in the lane being measured to the sum of the powers of all the other lanes is greater than 20 dB (see ITU-T G.959.1 Annex B). The lanes not under test shall be operating with the test patterns mentioned in 3.1.

3.6.1. TDEC Conformance Test Setup

A block diagram for the TDEC conformance test is shown in Figure 2. Other measurement implementations may be used with suitable calibration.

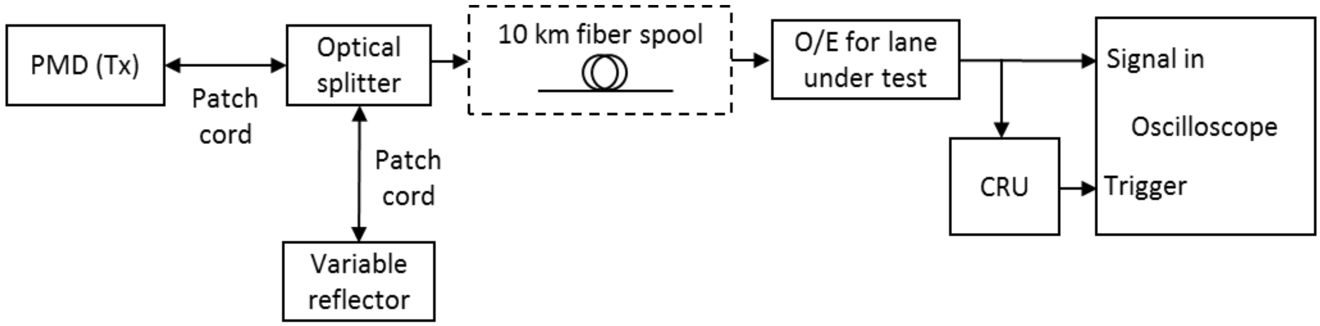


Figure 2: TDEC conformance test setup

Each optical lane is tested individually with all other lanes in operation. The optical splitter and variable reflector are adjusted so that each transmitter is tested with an optical return loss of 15.6 dB.

The combination of the O/E and the oscilloscope used to measure the optical waveform has a fourth-order Bessel-Thomson filter response with a bandwidth of 39.8 GHz. Compensation may be made for any deviation from an ideal fourth-order Bessel-Thomson response.

The clock recovery unit (CRU) has a corner frequency of 4 MHz and a slope of 20 dB/decade.

Two tests need to be performed: with and without a fiber of 10 km length specified in Table 7. The maximum of the single discrete reflections of the inserted fiber are specified in Table 5. The transmitter needs to pass both tests with a TDEC specified in Table 3.

3.6.2. Channel Requirements

The transmitter is tested using an optical channel that meets the requirements listed in Table 7.

Table 7: Channel Requirements for TDEC Test

Type	Dispersion (ps/nm)[a]		Insertion loss[b]	Optical return loss[c]
	Minimum	Maximum		
CWDM8	0.2325*λ*[1-(1324/ λ)^4]	0.2325*λ*[1-(1300/ λ)^4]	Minimum	15.6 dB

[a] The dispersion is measured for the wavelength of the device under test (λ in nm). The coefficient assumes 10 km for CWDM8.
[b] There is no intent to stress the sensitivity of the BERT's optical receiver.
[c] The optical return loss is applied at TP2, i.e. after a 2 meter patch cord.

3.6.3. TDEC Measurement Method

The TDEC measurement method shall follow IEEE Std 802.3-2015 Clause 95.8.5.2 with the following exceptions:

- The four vertical histograms are measured through the eye diagram are centered at 0.45 UI and 0.55 UI
- The BER is 2.4 x 10^{-4}
- The Q factor is 3.4917
- The formula for the received noise R is

$$R = \sqrt{N^2 + S^2}$$

where as in Clause 95.8.5.2, N represents the lesser of the left and right standard deviations σ_L and σ_R, and S is the standard deviation of the noise of the O/E and oscilloscope combination. Please refer to the source material for a more detailed description of the calculations.

3.7. Extinction Ratio

Extinction ratio is measured using the methods specified in IEC 61280-2-2, with the lanes not under test turned off.

3.8. Transmitter Optical Waveform (Transmit Eye)

Refer to IEEE Std 802.3-2012 Clause 88.8.8 with the following exceptions:

- The clock recovery unit's high-frequency corner bandwidth is 4 MHz
- The filter nominal reference frequency f_r is 39.8 GHz and the filter tolerances are as specified for STM-64 in ITU-T G.691.

3.9. Receiver Sensitivity

The nominal sensitivity of each receiver lane, is measured in OMA using the setup of Figure 3. The sensitivity must be corrected for any significant reference transmitter impairments including any vertical eye closure. It should be measured at the eye center or corrected for off- center sampling. The reference transmitter wavelength(s) shall comply with the ranges in Table 4.
The reference transmitter is a high-quality instrument grade device, which can be implemented by a CW laser modulated by a high-performance modulator. It should have the following basic requirements:

- The rise/fall times should be less than 6 ps at 20% to 80%.
- The output optical eye is symmetric and passes the transmitter optical waveform test of 3.8.
- In the center 10% region of the eye, the worst-case vertical eye closure penalty as defined in IEEE 802.3-2015 87.8.11.2 is less than 0.5 dB.
- Total jitter less than 0.2 UI peak-to-peak
- RIN of less than -140 dB/Hz.

Center of the eye is defined as the time halfway between the left and right sampling points within the eye where the measured BER is greater than or equal to 2.4×10^{-4}.

The clock recovery unit (CRU) used in the sensitivity measurement has a corner frequency of less than or equal to 4 MHz and a slope of 20 dB/decade. When using a clock recovery unit as a clock for BER measurement, passing of low frequency jitter from the data to the clock removes this low-frequency jitter from the measurement.

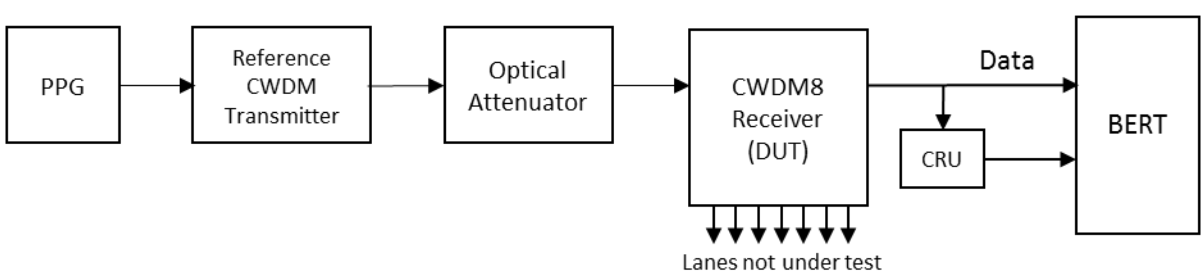


Figure 3: Test setup for receiver sensitivity

3.10. Stressed Receiver Sensitivity

Refer to IEEE Std 802.3-2015 Cl. 95.8.8 with the following exceptions:

- The test BER is 2 x 10^{-4}
- The stressed input signal shall be adjusted to provide the stressed eye closure, jitter, and stressed eye mask characteristics defined in Table 4 above.
- Each lane is tested individually with all other Rx and Tx channels turned ON and receiving or transmitting SSPR signals. The maximum OMA difference between the Rx lane under test and the other Rx lanes not under test is 4 dB.
- The fourth-order Bessel-Thomson filter has a 3 dB bandwidth of approximately 39 GHz.
- At least 2.0 dB of SEC (stressed eye closure) should be created by the selection of the appropriate band-width for the combination of the low-pass filter and the E/O converter

4. Fiber Optic Cabling Model

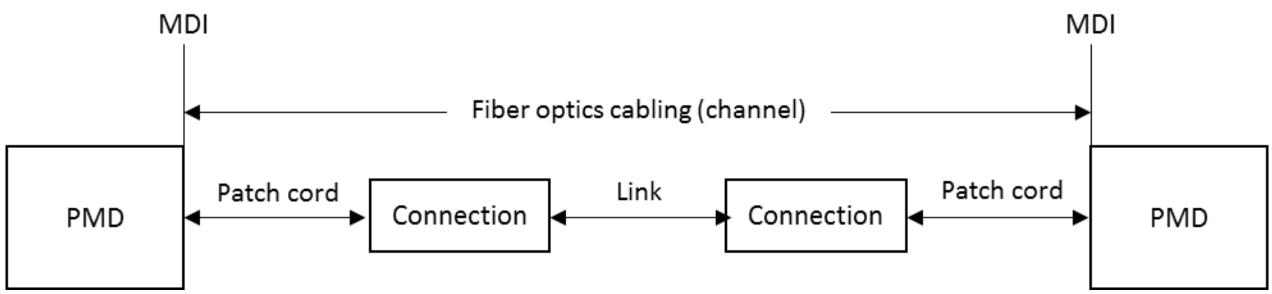


Figure 4: Fiber optic cabling model

The channel insertion loss is given in Table 8. A channel may contain additional connectors as long as the optical characteristics of the channel, such as attenuation, dispersion, reflections and polarization mode dispersion meet the specifications. Insertion loss measurements of installed fiber cables are made in accordance with IEC 61280-4-2 using the one-cord reference method. The fiber optic cabling model (channel) defined here is the same as a simplex fiber optic link segment. The term channel is used here for consistency with generic cabling standards.

Table 8: Fiber optic cabling (channel) characteristics

Description	CWDM8	Unit
Operating distance	10	km
Channel insertion loss max[a,b]	6.3	dB
Channel insertion loss min	0	dB
Positive dispersion[b] (max)	96.4	ps/nm
Negative dispersion[b] (min)	-59.3	ps/nm
DGD_max[c]	3	ps
Optical return loss (min)	15.6	dB

(a) These channel loss values include cable, connectors and splices.
(b) Over the wavelength range 1264.5 to 1417.5 nm.
(c) Differential Group Delay (DGD) is the time difference at reception between the fractions of a pulse that were transmitted in the two principal states of polarization of an optical signal. DGD_max is the maximum differential group delay that the system must tolerate.

5. Characteristics of the Fiber Optic Cabling (Channel)

5.1. Optical Fiber Cable

The fiber optic cable requirements are satisfied by cables containing

- IEC 60793-2-50 type B1.3 single mode fiber, or equivalently ITU-T G.652 types C and D (low water peak single mode fiber), or
- IEC 60793-2-50 type B6_a1 and B6_a2 single mode fiber, or equivalently ITU-T G.657 types A1 and A2 (bend insensitive single mode fiber with low water peak)

Table 9: Fiber characteristics

Description	Value	Unit
Nominal fiber specification wavelength	1310	nm
Cabled optical fiber attenuation (max)	0.5[a]	dB/km
Zero dispersion wavelength (λ_0)	$1300 \leq \lambda_0 \leq 1324$	nm
Dispersion slope (max) (S_0)	0.093	ps/nm^2·km

[a] The 0.5 dB/km attenuation is provided for Outside Plant cable as defined in ANSI/TIA 568-C.3

5.2. Optical Fiber Connection

An optical fiber connection, as shown in Figure 4, consists of a mated pair of optical connectors.

5.2.1. Connection Insertion Loss

The maximum link distances for single-mode fiber are calculated based on an allocation of 3 dB total connection and splice loss. For example, this allocation supports 6 connections with an average insertion loss per connection of 0.5 dB. Connections with different loss characteristics may be used provided the requirements of Table 8 are met.

5.2.2. Maximum Discrete Reflectance

The maximum discrete reflectance shall be less than -35 dB.

5.3. Medium Dependent Interface (MDI) Requirements

The PMD is coupled to the fiber optic cabling at the MDI. The MDI is the interface between the PMD and the “fiber optic cabling” (as shown in Figure 4). Examples of an MDI include the following:

a. Connectorized fiber pigtail
b. PMD receptacle

When the MDI is a connector plug and receptacle connection, it shall meet the interface performance specifications of IEC 61753-1-1 and IEC 61753-021-2.

Note: Transmitter compliance testing is performed at TP2, i.e. after a 2 meter patch cord, not at the MDI.

6. CWDM8 Optical Transceiver Color Coding

Transceiver modules compliant to the CWDM8 MSA Specifications use a color code to indicate the application. This color code can be on a transceiver module bail latch, pull tab, or other visible feature of the module when installed in a system. The color code scheme is specified below.

Color Code	Application
Light Purple, Pantone 2072C	400 Gb/s CWDM8 10 km reach